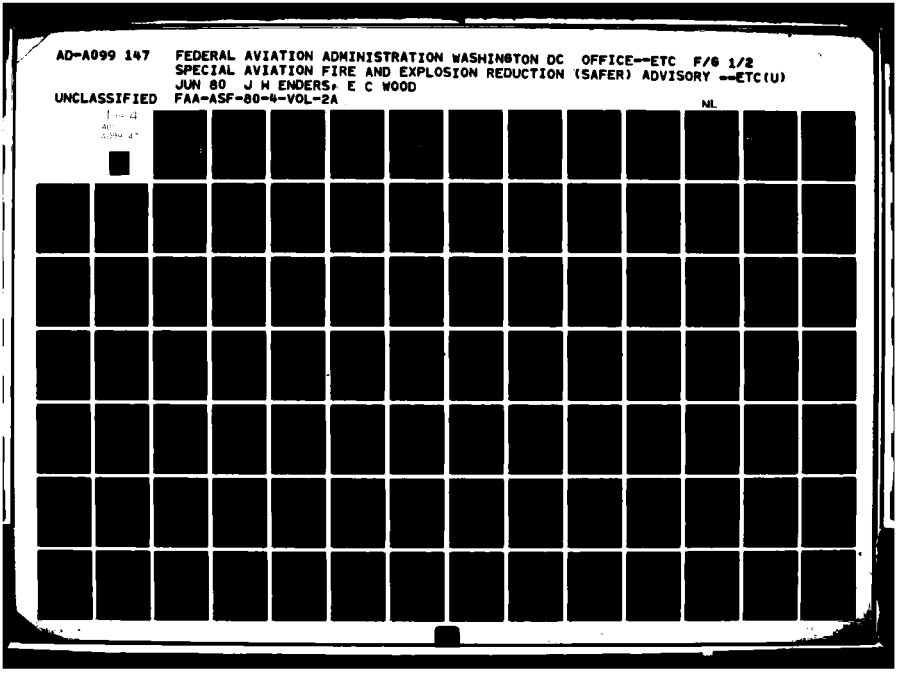
AD-A099 147 FEDERAL AVIATION ADMINISTRATION WASHINGTON DC OFFICE--ETC F/G 1/2
SPECIAL AVIATION FIRE AND EXPLOSION REDUCTION (SAFER) ADVISORY --ETC(U)
JUN 80 J W ENDERS, E C WOOD
UNCLASSIFIED FAA-ASF-80-4-VOL-2A NL



FAA-ASF-80-4

U.S. Department of Transportation
Federal Aviation Administration

Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee

Office of Aviation Safety
Washington, D.C. 20591

Final Report
Volume IIA

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June 26, 1978 through
June 26, 1980

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-ASF-80-4—Vol- IIA 2A		
4. Title and Subtitle FINAL REPORT OF THE SPECIAL AVIATION FIRE AND EXPLOSION REDUCTION (SAFER) ADVISORY COMMITTEE		5. Report Date June 26, 1980
		6. Performing Organization Code ASF-300
7. Author(s) J. H. Enders (Chairman), E. C. Wood (Executive Dir.)		8. Performing Organization Report No
9. Performing Organization Name and Address		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
		13. Type of Report and Period Covered Final Report June 26, 1978 - June 26, 1980
12. Sponsoring Agency Name and Address Office of Aviation Safety Federal Aviation Administration U.S. Department of Transportation Washington, D.C. 20591		14. Sponsoring Agency Code ASF-1

15. Supplementary Notes

16. Abstract

The Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee and its technical supporting groups spent nearly 13 months from May 1979 through June 1980 examining the factors affecting the ability of the aircraft cabin occupant to survive in the post-crash fire environment and the range of solutions available.

Presentations were made to the SAFER Committee by Committee members, technical supporting groups, the FAA, citizens and private firms. The broadly-constituted body of information developed and presented to the Committee formed the basis for Committee Findings and Recommendations.

This volume contains technical subcommittee submital related to interior cabin material's flammability, short term, solutions to the fire hazard and recommendations on Post Crash Fire Reduction.

17. Key Words		18. Distribution Statement
Post Crash	Cabin Materials	Document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161
Inflight Fire	Fire Safety	
SAFER	Occupant Survival	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

VOLUME II-A

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Escape Slides Report

Passenger Smoke Hoods Briefing

Research & Development Review Subgroup Report

Accident Statistics Review Subgroup Report

POST-CRASH FIRE HAZARD REDUCTION

Technical Group on Post-Crash Fire Hazard-Summary Report

Post-Crash Fire Hazard Sub-Groups

Explosion Suppression Report

Crash Resistant Fuel Tank Report

Anti-Misting Fuels Report

COMPANY PRESENTATION TO SAFER COMMITTEE

Boeing-Research & Development of Compartment Interiors Materials

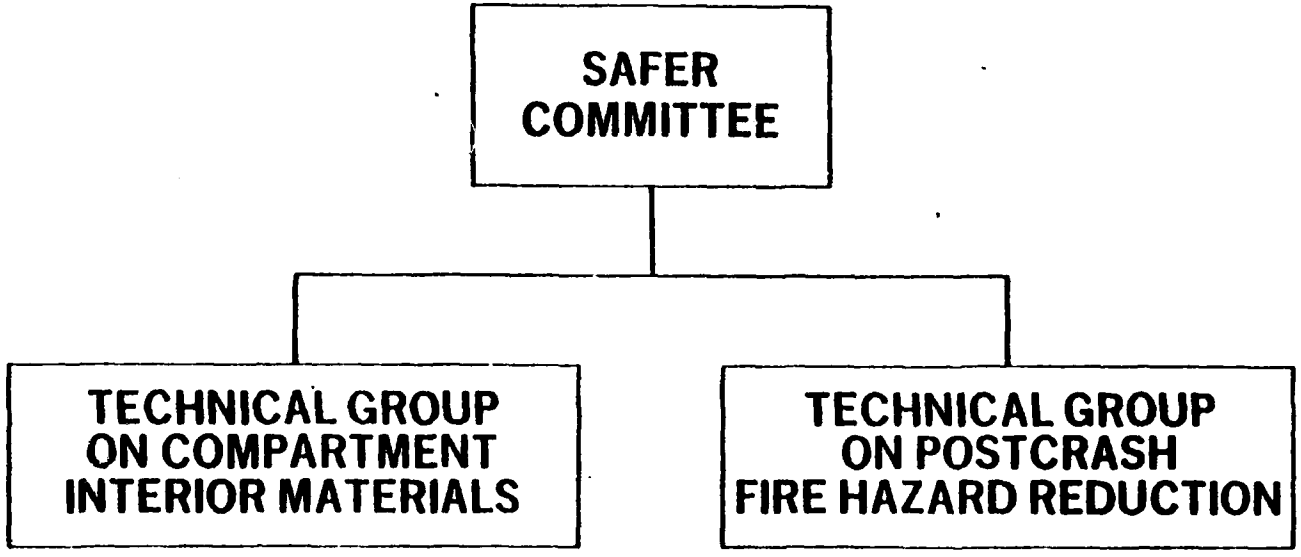
Lockheed- Fire Safety Improvement

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SUMMARY REPORT

SAFER TECHNICAL GROUP ON COMPARTMENT INTERIOR MATERIALS

27 SEPTEMBER 1979


SAFER COMMITTEE
TECHNICAL GROUP ON COMPARTMENT INTERIOR MATERIALS
TECHNICAL GROUP ON POSTCRASH FIRE HAZARD REDUCTION

SAFER MATERIALS TECHNICAL GROUP

SCOPE OF ACTIVITIES

RESTRICTED TO TRANSPORT AIRCRAFT
RESTRICTED TO POSTCRASH FIRE SCENARIO
INCLUDES ACTIVITIES PERTAINING TO:

- HUMAN TOLERANCES
- CABIN INTERIOR CONSTRUCTION MATERIALS
- MATERIALS EVALUATION AND ACCEPTANCE TESTING
- CABIN INTERIOR CONSTRUCTION SYSTEMS
- IGNITION AND HEAT SOURCES
- PROTECTION SYSTEMS
- PASSENGER CARRY-ON MATERIALS
- HEAT RESISTANCE OF EVACUATION SLIDES
- TRASH MANAGEMENT SYSTEMS
- ANALYTICAL STUDIES — FULL-SCALE FIRE SCENARIO

SAFER MATERIALS TECHNICAL GROUP

INITIAL OBJECTIVES

EVALUATE PERTINENT FAR'S

EVALUATE PERTINENT R&D PROGRAMS

- FAA FUNDED
- FAA CONDUCTED
- OTHER GOVERNMENT AND INDUSTRY

SUBMIT PRELIMINARY FINDINGS BY OCTOBER 1, 1979 INCLUDING:

- RECOMMENDATIONS AS TO SHORT-TERM RULE MAKING OR OTHER ACTION
- ANY INITIAL RECOMMENDATIONS TO REDIRECT, MODIFY, AND/OR FUND EXISTING/NEW R&D PROGRAMS

OBTAIN MAIN COMMITTEE ENDORSEMENT OF LONG-TERM OBJECTIVES

OBTAIN MAIN COMMITTEE GUIDANCE FOR OVERALL APPROACH

SAFER MATERIALS TECHNICAL GROUP

LONG-TERM OBJECTIVES

ESTABLISH HUMAN TOLERANCES AND PROTECTIVE MEASURES

- **FIRE**
- **IRRITANTS/INTOXICANTS**
- **SMOKE**
- **TOXICITY**

IMPROVED CABIN MATERIALS

- ***TRANSPARENCES***
- **THERMOFORMING PLASTICS**
- **FABRICS**
- **CUSHIONS**
- **DECORATIVE PLASTICS**
- **FLOOR COVERINGS**
- **IMPROVED CONSTRUCTION SYSTEMS**

DEVELOP SIMPLE RELIABLE MATERIALS EVALUATION AND ACCEPTANCE TESTS

IMPROVED FIRE DETECTION AND SUPPRESSION SYSTEMS

IMPROVED FIRE CONTAINMENT SYSTEMS

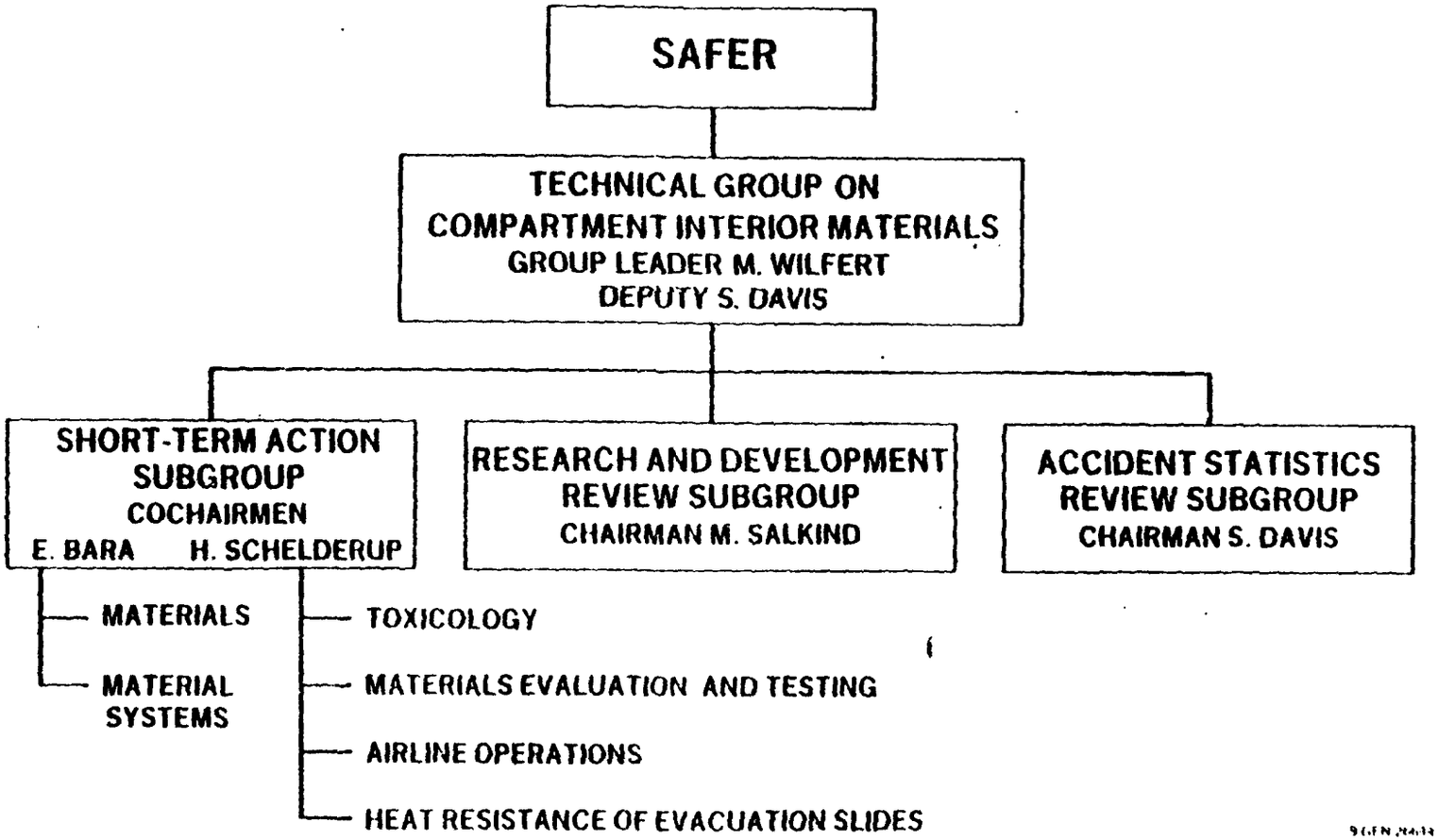
EVALUATE TRASH MANAGEMENT SYSTEMS

IMPROVED EVACUATION SYSTEMS

INVESTIGATE MEANS FOR SMOKE CONTROL

SUBMIT RECOMMENDATIONS FOR LONG-TERM OBJECTIVES TO SAFER ADVISORY COMMITTEE BY JUNE 1980

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MATERIAL
SYSTEMS
TOXICOLOGY
MATERIALS EVALUATION AND TESTING
AIRLINE OPERATIONS
HEAT RESISTANCE OF EVACUATION SLIDES

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SUBGROUP REPORTS

ACCIDENT STATISTICS REVIEW

RESEARCH AND DEVELOPMENT REVIEW

SHORT-TERM ACTION

ACCIDENT STATISTICS REVIEW SUBGROUP

STATUS REPORT

CONTROVERSIAL STATISTICS

FIRE FATALITIES AND CAUSES

PRELIMINARY SURVEY — 1959 TO 1975

- FIRE CAUSED DEATHS
- CABIN INTERIOR MATERIALS INVOLVEMENT?

DISTRIBUTED FOR STUDY AND REFINEMENT

- CLARIFICATION OF DETAILS
- ELIMINATION OF NONPERTINENT INCIDENTS
- INCLUSION OF ADDITONAL INCIDENTS

COMMITTEE MEETING EARLY OCTOBER

IATA DATA

RESEARCH AND DEVELOPMENT REVIEW SUBGROUP

MEETING 13 AND 14 AUGUST

REVIEWED CURRENT AND PLANNED R&D PROGRAMS

- MATERIALS DEVELOPMENT
- MATERIALS TESTING
- FIRE MODELING

FUNDING

	1979	1980
• DOT (FAA AND OTHERS)	2150K	2800K
• NASA	1485	895
• THREE TRANSPORT MANUFACTURERS	2200	1900
• SUPPLIER INDUSTRIES	EST. TO BE IN EXCESS OF $5M/YEAR	

FINAL REPORT — JUNE 1980

SUBGROUP ON R&D REVIEW

MATERIALS DEVELOPMENT

EXISTING MATERIALS

- PERFORM WELL
- CONTINUE DEVELOPMENT
  - DECORATIVE INKS AND FILMS ON CABIN INTERIOR SURFACES
  - SEAT CUSHIONS AND ARM RESTS
  - FLOOR COVERINGS AND DRAPES
  - WINDOW MATERIALS
  - EVACUATION SLIDES

SUBGROUP ON R&D REVIEW

CRITERIA FOR DESIGN

LIMITING FACTOR — CRITERIA FOR DESIGN

THREAT DEFINITION

- SURVIVABLE TAKEOFF OR LANDING
- FUSELAGE INTACT
- DOOR SIZE OPENINGS
- EXTERNAL FUEL FIRE

FULL-SCALE TESTS TO PROVIDE DATA FOR COMPLETE THREAT DEFINITION

SYSTEMS APPROACH

- HAZARD ANALYSIS
- HEAT, FLAME SPREAD, SMOKE AND TOXIC GASES AND THEIR INTERACTION
- CABIN FIRE MANAGEMENT AND EVACUATION CONSIDERATIONS
- MATERIALS IMPROVEMENT VERSUS FUEL FIRE SUPPRESSION

SUBGROUP ON R&D REVIEW

FIRE MODELING

GOAL: ANALYTICALLY DESCRIBE A FIRE AND ITS PROGRESS

- DESIGNING INTERIORS
- SELECTING MATERIALS

EARLY STAGES OF DEVELOPMENT

COORDINATE AND ACCELERATE DEVELOPMENT

LINK MODEL DEVELOPMENT TO TESTING

SCHEDULE

- USABLE PRELIMINARY ANALYSIS (2 YEARS)
- COMPREHENSIVE ANALYTICAL METHODOLOGY (5 YEARS)

SUBGROUP ACTIVITY BEFORE JUNE 1980

- NEED FOR HUMAN RESPONSE MODEL
- STUDY FEASIBILITY OF PHYSICAL FIRE MODELING

SUBGROUP ON R&D REVIEW

TESTING

FULL-SCALE AND MOCKUP TESTING REQUIRED BECAUSE THERE IS A LACK OF RELIABLE PREDICTIVE METHODS

- QUANTITATIVE DESIGN REQUIREMENTS FOR THE POSTCRASH FIRE SCENARIO
- REALISTIC EVALUATION OF CURRENT AND NEW MATERIALS SYSTEMS

LAB TESTS AND FULL-SCALE/ACCIDENT PERFORMANCE NEED EXTENSIVE DEVELOPMENT

- TOXICITY/LIFE HAZARD RELATIONSHIP
- CORRELATION — ANIMAL/CHEMICAL TESTS WITH HUMAN BEHAVIOR

SUBGROUP ON R&D REVIEW

OTHER ISSUES

NEED AN ON-GOING FORUM

- ASTM?
- GOVERNMENT COMMITTEE?
- SAE?
- NFPA?
- OTHER?

SHORT-TERM ACTION SUBGROUPS

MATERIALS AND MATERIALS SYSTEMS

TOXICOLOGY

OPERATIONS

HEAT RESISTANCE OF SLIDES

MATERIALS EVALUATION AND TESTING

MATERIALS AND MATERIALS SYSTEMS

33 SUBGROUP MEMBERS

APPROACH

- SOLICITED COMMENTS FOR RECOMMENDATIONS RELATED TO MATERIALS AND MATERIAL SYSTEMS
- TWO-DAY WORKING SUBGROUP MEETING

SHORT-TERM RECOMMENDATIONS

- UTILIZE THE FAR FLAMMABILITY TEST PENDING DEVELOPMENT OF A LABORATORY TEST THAT CORRELATES WITH FULL-SCALE TESTING
- THE FAR TEST SHOULD BE MODIFIED BY THE ASTM-F7 COMMITTEE FOR EVALUATING CERTAIN THERMOPLASTICS AND FOAMS
- AN INNER LINER FOR THE SEAT CUSHIONS BE DEVELOPED TO PROTECT PRESENT POLYURETHANE FOAM CUSHION MATERIAL

LONG-TERM RECOMMENDATIONS

- CONTINUE DEVELOPMENT OF THE POLYIMIDE AND POLYPHOSPHAZINE FOAMS
- CONTINUE DEVELOPMENT OF A MATERIALS DATA BANK

TOXICOLOGY

8 SUBGROUP MEMBERS

APPROACH

- SOLICITED COMMENTS FROM SUBGROUP MEMBERS AND OTHERS ON A DRAFT TOXICITY TEST
- DEVELOPED RESPONSE VIA CORRESPONDENCE AND TELEPHONE
- DRAFTED FINAL RESPONSE IN WORKING SUBGROUP MEETING

CONCLUSIONS

THE COMMITTEE:

- REAFFIRMS THE INTERACTIVE NATURE OF FLAMMABILITY, HEAT, SMOKE, AND TOXIC FACTORS, AND THAT THE USE OF STATE-OF-THE-ART MATERIALS TO REDUCE THE INCIDENCE AND SEVERITY OF FIRE REDUCES THE TOXIC THREAT
- RECOGNIZES THE ILL-DEFINED ROLE OF TOXICITY IN PASSENGER SURVIVABILITY
- CONCLUDES THAT THERE IS AT PRESENT NO ACCEPTABLE TOXICITY TEST FOR MATERIAL SELECTION

TOXICOLOGY (CONT)

RECOMMENDATIONS

SHORT-TERM RULEMAKING

- NO REGULATORY ACTION IS JUSTIFIED BASED ON TOXICITY TESTS USING CHEMICAL OR BIOLOGICAL CRITERIA
- RECONSIDER THE USE OF AVAILABLE PERSONAL PROTECTION DEVICES

LONG-TERM ACTIVITY

- SUPPORT INCREASED RESEARCH TO IDENTIFY AND UNDERSTAND THE BIOLOGICAL, CHEMICAL, AND PHYSICAL FACTORS THAT MUST BE INTEGRATED INTO COMPREHENSIVE FIRE RISK ASSESSMENTS FOR MATERIALS IN SPECIFIC USE CONFIGURATIONS
- PROVIDE OPEN FORUMS, DOCUMENTS, AND PRESENTATIONS TO MAKE THIS SUBJECT MORE UNDERSTANDABLE TO REGULATORY BODIES AND TO THE PUBLIC

AIRLINE OPERATIONS
3 SUBGROUP MEMBERS

APPROACH

- TELEPHONE DISCUSSION
- WORKING GROUP MEETING 29 AUGUST 1979

RECOMMENDATIONS

- SHORT-TERM
  - — ADVISORY INFORMATION ON CARRY-ON MATERIALS

EVACUATION SLIDES
FIVE SUBGROUP MEMBERS

APPROACH

- REVIEW OF CURRENT TESTS
- TWO-DAY WORKING SUBGROUP MEETING
  - METHODS AND TEST PROCEDURES REVIEWED
  - DEVELOPMENT PLAN FORMULATED

RECOMMENDATIONS

- NO SHORT-TERM RULES
- THREE-PHASE TEST METHOD DEVELOPMENT (FUNDED AND UNDERWAY)
  - DEVELOP PRACTICAL LABORATORY TEST (JANUARY 1980)
  - CONDUCT TEST PROGRAM TO DETERMINE LABORATORY TEST REQUIREMENTS (MAY 1980)
  - EVALUATE STATE-OF-THE-ART REFLECTIVE COATINGS (MAY 1980)

MATERIALS EVALUATION AND TESTING

16 SUBGROUP MEMBERS

APPROACH —

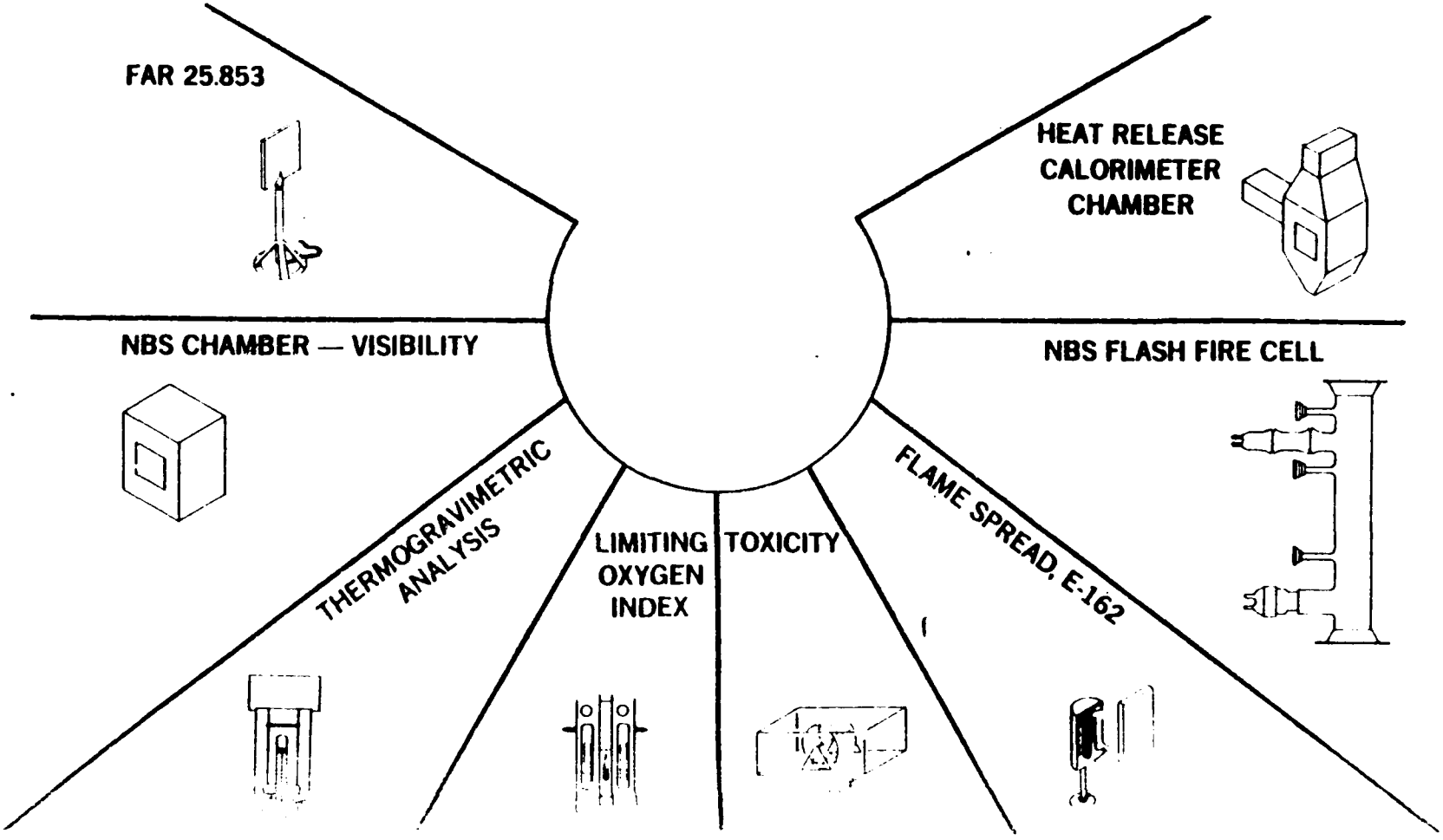
- 2-DAY WORKING GROUP MEETING
  - REVIEW TEST METHOD HISTORY
  - REVIEW EXISTING TEST METHODS — REGULATORY AND OTHERS
  - PRIORITIZE OBJECTIVES
  - RATE TEST METHODS BASED ON OBJECTIVES

MATERIALS EVALUATION AND TESTING
SUBGROUP OBJECTIVES

IN ORDER TO INCREASE AVAILABLE PASSENGER EGRESS TIME:

- TEST METHODOLOGY SHOULD RELATE TO HUMAN HAZARD
- RESULTS OF TESTS SHOULD SHOW MATERIAL IMPROVEMENT WITH RESPECT TO FIRE HAZARD
- RESULTS OF TESTS WHEN APPLIED TO MATERIAL SELECTION CAN BE VERIFIED AS USED IN FULL-SCALE TESTS
- TEST METHODOLOGY SHOULD COMBINE EVALUATION OF FLAMMABILITY, SMOKE, AND GAS PRODUCTS
- TEST SPECIMEN SHOULD REPRESENT THE END USE ITEM
- MATERIALS RATING SYSTEM MUST BE QUANTITATIVE AND REPRODUCIBLE
- TEST TECHNIQUE SHOULD BE REASONABLY AVAILABLE AND LOW IN COST
- TEST METHOD MUST BE AVAILABLE BY 1 OCTOBER 1979

MATERIAL EVALUATION TEST METHODS



TEST METHOD RATINGS

MAXIMUM SCORE 620

OBJECTIVES	WEIGHT	FAR				NBS SMOKE				ASTM E162		OSU		TGA/ DSC		LOI		NASA T-3	
		CURRENT		MOD		CURRENT		MOD											
1	10	3.6	36	4.6	46	4.6	46	5.8	58	5.6	56	9.1	91	3.3	33	3.2	32	3.5	35
2	10	6.9	69	5.1	51	5.1	51	6.6	66	5.9	59	9.0	90	3.8	38	3.4	34	4.9	49
3	10	3.3	33	4.3	43	4.3	43	5.7	57	5.0	50	8.5	85	2.6	26	2.4	24	4.4	44
4	8	1.0	8	1.7	14	3.2	26	4.5	36	4.6	37	8.2	66	2.1	17	1.3	20.4	2.3	18.4
5	9	5.9	53	5.9	53	5.8	52	6.1	55	7.6	68	8.1	73	1.1	10	0.9	8.1	6.8	61.2
6	8	6.9	55	8	64	7.1	57	6.4	51	6.6	53	7.2	58	6.6	53	7.4	59.2	5.1	40.8
7	7	9.8	69	7.8	55	8.4	59	5.4	38	8.2	57	4.8	34	5.3	37	8.1	56.7	3.5	24.5
Σ			323		326		334		361		380		497		214		224.4		273
B	YES	9		2		9		1		9		3		3		9		3	
	NO	0		3		0		7		0		6		5		0		4	

MATERIALS EVALUATION AND TESTING

(CONTINUED)

CONCLUSIONS

- THE OSU HEAT RELEASE TEST METHODOLOGY APPEARS TO PROVIDE THE MOST PROMISE FOR LONG-TERM APPLICATION
- COMMITTEE AGREED THAT THE FAR 25 BUNSEN BURNER TEST IS A VALID IGNITABILITY TEST FOR MOST MATERIALS
- THE NBS SMOKE CHAMBER HAS BEEN SUCCESSFULLY APPLIED AS AN INFORMAL SCREENING TEST FOR WIDE-BODY INTERIOR MATERIALS

MATERIALS EVALUATION AND TESTING

(CONTINUED)

RECOMMENDATIONS

- LONG-TERM
  - EXPEDITE THE DEVELOPMENT OF THE OSU CHAMBER AND EVALUATE ITS POTENTIAL USE AS A REGULATORY TOOL FOR FLAMMABILITY, SMOKE, AND GAS CONCENTRATION CRITERIA WITH THREE YEARS.
    - EARLY IMPLEMENTATION PLAN MUST BE DEVELOPED (DEC 79)
    - INDUSTRY/GOVERNMENT TEST DEVELOPMENT COMMITTEE TO BE ESTABLISHED

MATERIALS EVALUATION AND TESTING

(CONTINUED)

RECOMMENDATIONS (CONT)

- SHORT-TERM ACTION
  - RETAIN FAR 25 BUNSEN BURNER TEST
  - MODIFY FAR 25 TEST METHOD FOR MATERIALS THAT DRIP AND MELT AWAY FROM THE FLAME
  - ESTABLISH THE NBS SMOKE CHAMBER AS A FORMAL SCREENING TEST

SUMMARY OF RECOMMENDATIONS

LONG-TERM CONSIDERATIONS

- EXPEDITE AND COORDINATE C-133 AND SIMILAR FULL-SCALE FIRE TESTS
- DEFINE A DESIGN POSTCRASH FIRE SCENARIO
- ESTABLISH CONTRIBUTION OF CABIN INTERIOR MATERIALS RELATIVE TO THE POSTCRASH FIRE HAZARD
- EXPEDITE THE DEVELOPMENT OF THE OSU CHAMBER AND EVALUATE ITS POTENTIAL USE AS A REGULATORY TOOL
- COMPLETE PRELIMINARY EVALUATION OF THE TEST PROCEDURE AND PRESENT MATERIALS FOR EVACUATION SLIDES BY MAY 1980
- ACCELERATE RESEARCH EFFORT TO IDENTIFY AND UNDERSTAND THE BIOLOGICAL, CHEMICAL, AND PHYSICAL FACTORS THAT MUST BE INTEGRATED INTO COMPREHENSIVE FIRE RISK ASSESSMENTS FOR MATERIALS IN SPECIFIC USE CONFIGURATION
- PROMOTE OPEN FORUMS, DOCUMENTS AND PRESENTATIONS TO MAKE THE SUBJECT OF TOXICOLOGY MORE UNDERSTANDABLE
- DEVELOP CABIN INTERIOR MATERIAL DATA BANK
- CONTINUE DEVELOPMENT OF LOW-SMOKING FIRE-RESISTANT SEAT FOAMS

9 GEN 2670E

SUMMARY OF RECOMMENDATIONS

(CONTINUED)

IMMEDIATE ACTION

- RETAIN FAR 25 BUNSEN BURNER TEST
- MODIFY FAR 25 TEST METHOD FOR MATERIALS THAT DRIP AND MELT AWAY FROM THE FLAME
- ESTABLISH THE NBS SMOKE CHAMBER AS A FORMAL SCREENING TEST
- INCORPORATE SEAT CUSHION INNER LINERS TO PROTECT PRESENT POLYURETHANE FOAM CUSHIONING MATERIAL
- DEVELOP AND ISSUE ADVISORY INFORMATION ON CARRY-ON MATERIALS
- REEVALUATE USE OF PERSONAL PROTECTION DEVICES

PERSPECTIVE

CURRENT PRODUCTION AIRPLANE CABIN INTERIOR MATERIALS ARE STATE-OF-THE-ART AND PROVIDE A HIGH LEVEL OF FIRE SAFETY.

AS DEMONSTRATED IN THE PAST, IMPROVEMENTS IN MATERIALS WILL BE INCORPORATED ON AIRCRAFT AS NEW MATERIALS ARE DEVELOPED, BUT IT IS NOT FELT THAT ADDITIONAL ACCELERATED PROGRAMS FOR MATERIALS RESEARCH AND DEVELOPMENT ARE WARRANTED

CURRENT TEST METHODS CANNOT BE USED TO ESTABLISH MATERIALS CONTRIBUTION TO CABIN OCCUPANT SURVIVABILITY AT THIS POINT IN TIME.

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PERSPECTIVE

(CONTINUED)

FUTURE REGULATORY ACTION SHOULD BE RELATED TO CABIN OCCUPANT SURVIVABILITY IN THE POSTCRASH FIRE SCENARIO

FURTHER SAFETY IMPROVEMENT EFFORTS SHOULD BE OBTAINED BY USING A SYSTEMS APPROACH AS OPPOSED TO A SEGMENTED APPROACH

THE FAA ADVISE THE APPROPRIATE CONGRESSIONAL COMMITTEES AND OTHERS AS TO THE FINDINGS AND RECOMMENDATIONS OF THIS COMMITTEE

AN ON-GOING FORUM (FAA, NTSB, NASA, SAFER, ASTM, OR ?) SHOULD BE MAINTAINED TO COORDINATE AIR TRANSPORT FIRE SAFETY RESEARCH AND TECHNOLOGY PLANNING AND ADVISE APPROPRIATE GOVERNMENTAL, CONGRESSIONAL, AND OTHER GROUPS OF STATUS, IMPROVEMENTS, AND GOALS.

SAFER TECHNICAL GROUP
COMPARTMENT INTERIOR MATERIALS

REPORT
SHORT-TERM ACTION SUBGROUP
MATERIALS SYSTEMS

E.BARA / J.PARKER
CO-CHAIRMEN

SUMMARY

- THIS REPORT PRESENTS THE RECOMMENDATIONS MADE BY THE MATERIALS SYSTEMS SUBGROUP OF THE SAFER TECHNICAL GROUP ON COMPARTMENT INTERIOR MATERIALS ADDRESSING BOTH IMMEDIATE AND LONG TERM RECOMMENDATIONS.

LIST OF PARTICIPANTS

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GENE BARA	BOEING
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APPROACH

- INTRODUCTION
- MATERIAL ASSESSMENT
- MATERIALS CHARACTERISTICS

  (TABLE I)

INTRODUCTION

- IN RESPONSE TO THE AIRCRAFT FIRE PROBLEM, THE MATERIALS AND MATERIALS SYSTEMS SUB-GROUP CONSIDERED WHAT RECOMMENDATIONS COULD BE MADE TO THE FAA FOR REGULATIONS ADDRESSING THE PROBLEM OF THE POST CRASH SURVIVABLE FUEL FIRE.

- THE WORKING GROUP ADDRESSED BOTH SHORT TERM BY OCTOBER 1, 1979 RECOMMENDATIONS AND LONG TERM RECOMMENDATIONS FOR SUBMITTAL TO THE SAFER COMMITTEE.

MATERIALS ASSESSMENT

- MATERIALS USED IN TODAYS PRODUCTION OF COMMERCIAL JET TRANSPORTS ARE THE BEST PRODUCTION AVAILABLE MATERIALS BEING MARKETED BY THE PLASTICS AND FABRICS (FIBERS) INDUSTRIES.
- THESE MATERIALS ARE REQUIRED TO MEET THE FAA'S FAR 25.853 AND FAR 25.855 BUNSEN BURNER TESTS FOR IGNITABILITY, SELF-EXTINGUISHMENT AND BURN THRU.
- IN ADDITION THESE MATERIALS MUST MEET STRENGTH AND DURABILITY REQUIREMENTS AS WELL AS PRODUCIBILITY REQUIREMENTS.
- ALSO THE AIRFRAME MANUFACTURERS ARE MEASURING OTHER FLAMMABILITY PROPERTIES UTILIZING THE ASTME-162 FLAME SPREAD, AND EVALUATING SMOKE PRODUCTION AND GAS EVOLUTION USING THE NBS SMOKE CHAMBER AND THE OSU RELEASE CALORIMETER IN AN ATTEMPT TO USE MATERIALS THAT WILL NOT IMPACT EGRESS TIME.
- THIS IS BEING DONE FOR ALL MAJOR USAGE MATERIALS IN THE PASSENGER COMPARTMENT, THE FLIGHT DECK AND THE CARGO COMPARTMENT.
- AN EXAMPLE OF MATERIALS TEST DATA USING VARIED TEST METHODS IS SHOWN IN TABLE 1.

MATERIALS CHARACTERISTICS

TABLE I

MATERIALS APPLICATIONS	FAR 25.853		NBS SMOKE Ds		ASTM E-162
	EXTINGUISH TIME SECONDS	BURN LENGTH INCHES	1.5 MIN.	4.0 MIN	FLAME SPREAD IS
DECORATIVE SIDEWALL SANDWICH PANEL	0-1	2.7 - 4.7	20-112	50-270	3-50
CARGO LINER LAMINATE	0-3	1.7 - 3.2	3.6-159	3.6-267	1-25
UPHOLSTERY FABRIC	1.5-4	2-2.8	18-106	45-220	N.A.
CARPET	2-13	1.3-2.2	31-42	251-381	N.A.

N.A. - NOT APPLICABLE

RECOMMENDATIONS

NO IMMEDIATE REGULATORY ACTION

- AT THIS POINT IN TIME WE FEEL IT IS NOT JUSTIFIED TO IMPOSE SHORT-TERM REGULATION CHANGES WITHOUT HAVING A SOUND TECHNICAL BASIS ON WHICH TO JUDGE THE SAFETY IMPROVEMENT.

- WE FEEL THAT A SOUND DEFINITION OF TESTS AND TEST METHODS NEEDS TO BE DEVELOPED THAT SIMULATE AND CORRELATE WITH THE FIRE ENVIRONMENT OF AN IMPACT SURVIVABLE POST CRASH FUEL FIRE.

- UNTIL THE ANALYSIS RELATING FULL SCALE TESTING WITH LABORATORY TESTING IS CORRELATED THIS COMMITTEE FEELS THAT THE MATERIALS CANNOT BE EVALUATED PROPERLY TO PROVIDE THE NECESSARY DATA RELATIVE TO MEASURABLE IMPROVEMENTS IN AIRCRAFT FIRE SAFETY.

RECOMMENDATIONS

AGRESSIVELY PURSUE SEAT CUSHION
MATERIAL PROTECTIVE MEASURES

- LINERS
- NEW CUSHION MATERIALS

- IT WAS THE OPINION OF THIS SUB-GROUP THAT AT THIS TIME THE FAR-25 - AMENDMENT 32 IS ADEQUATE TO DETERMINE THE BEST STATE-OF-THE-ART MATERIALS FROM A FLAMMABILITY STANDPOINT EXCEPT IN THE TESTING OF SEAT CUSHION COMPOSITES.

- WE FEEL THAT SOME DEGREE OF IMPROVED FLAMMABILITY OF SEAT CUSHIONS CAN BE OBTAINED BY STAGING DIFFERENT CUSHIONING MATERIALS.

- FOR THE SHORT-TERM WE RECOMMEND THAT AN INNER LINER OF THE CUSHION SUCH AS A LOW SMOKE PRODUCTION FOAM BE USED TO PROTECT THE POLYURETHANE FOAM.

- THE POSSIBILITY FOR A LONG RANGE SOLUTION FOR SEAT CUSHION COMPOSITES MAY RESULT FROM THE CONTINUED DEVELOPMENT OF FLEXIBLE POLYIMIDE AND POLYPHOSPHAZINE FOAM MATERIALS.

RECOMMENDATIONS

MATERIALS DATA BANK

- THIS SUB-GROUP FEELS THAT A MATRIX OF MATERIALS PROPERTIES WHICH IS RELATED AND CORRELATED WITH FULL SCALE FIRE TESTING BE DEVELOPED BY THE AIRCRAFT MANUFACTURERS AND SUPPLIERS, TO BE UTILIZED IN A DATA BANK SYSTEM CREATED BY NASA-AMES AND RECOMMENDS THAT THE DATA BANK BE CONTINUED BY THE FAA TO PROVIDE DATA TO THE INDUSTRY.

- THIS IS A LONG RANGE DEVELOPMENT RELATED TO BETTER UNDERSTANDING MATERIALS AND THEIR APPLICATION IN JET TRANSPORT AIRCRAFT.

MEMORANDUM

SUBJECT: Recommendations for immediate and for long-term activity to reduce toxic threat to postcrash fire survivability

TO: Co-Chairmen, Short-Time Action Sub-Group, SAFER Technical Group on Compartment Interior Materials

FROM: Ad hoc Committee on Toxicology

At the June 26-27, 1979, meeting of the SAFER Technical Group on Compartment Interior Materials, a Short-Time Action Sub-Group was established by the group leader and was charged with two major tasks:

1. Advise as to what can be done in the short-term; and
2. Establish a draft list of long-term objectives aimed at increasing survivability in the postcrash fire environment.

[illegible] a report to the Technical Group's consideration a response that addresses the toxicological aspects of the two tasks.

This committee submits the following draft recommendations for consideration by the SAFER Technical Group on Compartment Interior Materials.

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ITEM 1

CONSIDERATIONS FOR SHORT-TERM RULEMAKING

Recommendation A:

Reduction of the potential toxic threat from thermal decomposition products by controlled selection of interior materials on the basis of relative performance in a small-scale toxicity test with experimental animals cannot be recommended by this committee at this time.

Recommendation B:

For the purpose of material selection, assessment of relative toxicity from results of chemical analysis for selected components of thermal decomposition products cannot be recommended.

Recommendation C:

Although neither the absolute nor the relative magnitudes of the toxic threat of fire environments can be quantitated (for lack of a small-scale test procedure with demonstrated relevance and reliability) there are obvious and unquestionable means available at this time for reducing toxic threat in the posterash fire situation.

For any given fire scenario, the toxic threat of the resultant environment is:

1. A direct function of the total quantity and distribution of combustibles in the cabin,

2. An inverse function of the threshold decomposition temperature and subsequent rate of degradation of the involved materials,

3. Proportional to the time required to evacuate the aircraft, and

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4. Directly related to the total quantity of the cabin atmosphere that an escaping individual is forced by circumstance to inhale.

Therefore, despite the lack of a toxicity test methodology, it is possible to achieve a reduction in the total toxic potential by controlling other parameters.

This committee recommends that serious consideration be given to the potential for reducing the toxic threat and thereby increasing passenger survivability by implementing one or more of the following actions:

1. Restrict the quantity and local concentration of unnecessary combustibles in the passenger compartment (primarily "carry-on" and passenger service items).

2. Upgrade the flammability (ignitability) requirements for all compartment interior materials.

3. Decrease the potential impediments to a rapid evacuation.

4. Thoroughly evaluate existing "smoke hoods" and require their use if advantageous to survivability.

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ITEM 2

RECOMMENDED RESEARCH AREAS REQUIRING LONGER-TERM ACTIVITY AND SUPPORT IN ORDER TO IDENTIFY AND CONTROL THE TOXIC THREAT TO PASSENGER SURVIVABILITY

Areas specifically related to development of a relevant and reliable small-scale test for toxicity:

1. Identify appropriate species for animal model.
2. Identify physiological endpoint most appropriate to loss of escape potential.
3. Identify smoke components responsible for loss of escape potential.
4. Determine that, for each major class of toxic components, human responses can be suitably predicted from animal surrogate responses.
5. Determine relative contribution of toxic and noxious insults to loss of escape potential in test animal and in-humans.
6. Determine the relative importance of the several fire hazards, e.g., heat, smoke, and toxicity.
7. Define appropriate mode for thermal degradation of sample.
8. Determine the degree to which heat and toxicity interact.
9. Determine the contribution of scaling factors.
10. Estimate human tolerances to the individual hazards, and to their combinations.

Areas that influence toxicity indirectly:

1. Continue efforts directed toward fire control.
2. Continue research to expedite evacuation.
3. Continue efforts to reduce the quantity and degree of exposure of combustible items in passenger compartment.
    a. Use of fewer (or less-combustible) galley-associated items.

b. Stowage of galley (and other) wastes in fire-hardened compartments.

c. Decrease quantity of combustible liquids in cabin.

4. Continue research on smoke, heat, and toxic-gas protective devices for use during evacuation.

a. Investigate practicality of a portable modification of current passenger service mask.

5. Encourage material research to improve hazard properties other than toxicity.

a. Improve thermal stability.

b. Decrease evolution of optically dense smoke.

c. Decrease the combustible (organic) fraction of specific materials.

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MINUTES OF MEETING

SAFER SUBCOMMITTEE FOR

MATERIALS EVALUATION AND TESTING

AUGUST 16, 17, 1979

AMES RESEARCH CENTER

MINUTES OF MEETING OF

MATERIALS EVALUATION AND TESTING SUBCOMMITTEE

AUGUST 16 & 17, 1979

AMES RESEARCH CENTER

This group was designated as the "Materials Evaluation and Testing Subcommittee" by the Short Time Action Subgroup with the assignment of reporting to the SAFER Technical Group on Compartment Interior Materials during the week of September 25, 1979 concerning the two following items.

1. Feasibility of short-term rules for flammability and smoke.
2. List of long-term objectives to increase passenger survival time in the post-crash fire.

The subcommittee was made up of the members shown on Enclosure 1.

The meeting was convened at 8:30 a.m. (see Agenda, Enclosure 2) and the chairman made a short presentation on the committee tasks and the overall organization.

A review of the FAA hearings held in 1977 concerning conclusions as a basis for SAFER and industry needs was presented by Mr. Bob Sutton, Douglas Aircraft Company, to provide background information in support of the present meeting.

Mr. Henri Branting of FAA Headquarters then spoke on cabin materials standards from the point of view of rulemaking and discussed the pros and cons of an air worthiness standard pertaining to aircraft fire safety compared to a specific standard such as the FAR 25 Bunsen burner test.

The Chairman made a presentation on a recommended approach for the committee to follow which would not inhibit discussion or initiative, but would provide a systematic and reasoned approach to reaching decisions concerning the committee's major tasks. The recommended approach consisted of establishing objectives for new rule making based on expected results and available resources and classifying the objectives according to importance. The alternatives (potential tests for new rules) would then be evaluated against the objectives which would result in a numerical ranking of the alternatives and provide direction in selecting optimum alternatives.

The remainder of the morning was spent in discussing and selecting test objectives and ranking them according to importance. The seven objectives selected and their ranking and one mandatory requirement (availability of test method) are shown on Enclosure 3.

The afternoon consisted of presentations to the committee on candidate test methods. Mr. G. Sarkos then discussed the FAA proposed interim standards. A presentation was made by Mr. Ev Tustin of Boeing on a proposed crash fire scenario, and a description of the current status of the combined Hazard Index program was presented by Mr. Bob Sutton of Douglas.

After a short discussion, the meeting was adjourned until the next day. The meeting reconvened at 8:30 a.m. on August 17, 1979 and it was decided that the open time in the agenda for the morning should be used to evaluate the test alternatives against the previously agreed to objectives. A matrix was generated of the various test candidates versus the objectives, and the tests then were rated from 1 to 10, with the higher number being indicative of the

test closest to meeting a specific objective. Each member of the committee filled out an evaluation matrix, i.e., each test was given a number by the individual on how well, based in his judgment and experience, it met each objective. These numbers were then averaged, multiplied times the weight of each objective and then summed for an overall numerical rating for each test. The results of this evaluation are shown in Enclosure 4. The Ohio State University heat release apparatus received the highest score and the ASTM 162 radiant panel test was second.

Prior to this evaluation, the committee received written and verbal input recommending consideration for testing floor coverings in the NBS flooring radiant panel apparatus (ASTM method E-648 or NFPA No. 253-1978). The recommendation was discussed at length and the majority opinion was that the committee did not have enough members familiar with this test method to give it a valid evaluation when compared to the more familiar tests currently being used by most of the participants. Additionally, the philosophy of adding specialized tests for various applications versus one or two tests for all applications was discussed. The consensus of the committee was that a specialized test for floor coverings is not required.

Prior to discussing short and long-term recommendations the committee also discussed the potential of an airworthiness standard as reviewed in Mr. Henri Branting's FAA presentation and in more detail by Mr. Bob Sutton of Douglas.

The Materials Evaluation and Testing subcommittee recognizes that regulations based on go-no go material burn characteristics must be continually updated as materials continually improve.

In order to explore other possibilities, Enclosure 5 is a rephrasing of FAR 25.571 Fatigue Evaluation of Flight Structure as it might be adapted to a Fire Safety regulation pertaining to performance rather than material go-no go limits.

Sufficient testing standardization and analytical background to support this approach does not currently exist. The necessary technology is presently being partially developed and in the future when sufficient information is available to fully establish the future impact of this approach, an evaluation may be accomplished.

The committee agreed that this was an interesting and potentially viable approach and agreed to consider it further. At this time the committee returned to the task of making short and long-term recommendations based on the completed evaluation. Since the OSU test method best met the test objectives but will not be available by October 1, 1979 (from the standpoint of having test data on contemporary materials and finalizing test procedures), this test method was formulated into the following long-term recommendation.

> Expedite the development of the OSU chamber and evaluate its potential use as a test method tool for combined flammability, smoke, and gas concentration criteria within three years. A plan for implementation will be prepared by this committee by December 15, 1979 (contingent on approval of the recommendation by the SAFER Advisory Committee). The following organizations represented on the committee and having OSU chambers have agreed to participate in the development and evaluation: DuPont, FAA, Boeing, Douglas, Lockheed, National Bureau of Standards, Ohio State University, Southwest Research Institute, General Electric, and Owens Corning. Liaison will be maintained with the toxicity committee.

It was proposed that the ASTM E-162 radiant panel test be considered as an interim standard. Most of the subcommittee felt that the time required to develop the ASTM test for aircraft materials and acquire the data would be as long as for the OSU chamber. The subcommittee voted 7 to 5 against including the ASTM E-162 as an interim procedure.

As an interim measure it was recommended that the FAR 25 Bunsen burner test be modified to correct tests for materials affected by melting and dripping. The ASTM F-7 committee for Flammability of Aerospace Materials (represented by Dr. G. Nelson, Chairman of F-7 and on the subcommittee) agreed to study this problem and develop procedures to correct test deficiencies.

The subcommittee recognized the fact that the NBS smoke chamber test has been widely used by the FAA and the aircraft industry even though there is no current regulation requiring the test. The subcommittee, after a vote of 7 for and 5 against, recommended that the NBS smoke chamber test be standardized at 2.5 watts per sq. cm. in the flaming condition and adopted as a requirement for aircraft interior materials. Passing levels of smoke density for this test were discussed and it was agreed that these levels should be no more stringent than those numbers generated by existing materials used in contemporary wide body aircraft. Comments received subsequent to the meeting recommended that as the airframe manufacturer already perform this test and submit test data to the FAA that sufficient government control is already established. Further, the test does not meet the requirements of the objectives in that D_s levels from this test cannot be related occupant survivability in the post crash fire scenario.

The philosophy of the subcommittee with respect to the two recommendations for interim standards (improving FAR 25 and imposing a smoke test) is that these actions will not serve to improve aircraft materials or increase passenger survivability. However, the tests are more indicative of the tests currently being used for wide body aircraft and are more than required by current regulations. Adding these requirements increases the minimum material acceptance standards until the OSU chamber can be standardized for flammability, smoke and gas criteria.

At this point it was the opinion of the subcommittee that the assigned tasks had been completed to the extent possible at this time and the meeting was adjourned.

SUMMARY OF SUBCOMMITTEE RECOMMENDATIONS

LONG TERM - Expedite the development of the OSU chamber as a test method for combined flammability, smoke, and gas concentration criteria within three years.

APPROACH - If the recommendation is approved by the SAFER committee, a plan for implementation will be prepared by the subcommittee by December 15, 1979.

PARTICIPANTS - DuPont, FAA, Boeing, Douglas, National Bureau of Standards, Ohio State University, Southwest Research Institute, Lockheed, General Electric, and Owens Corning represented on the subcommittee and having OSU chambers agreed to participate in the development. Because of the practical need to eventually control material toxicity through the use of gas concentration levels the subcommittee recommends that liaison be maintained with the toxicity subcommittee.

SHORT TERM

FLAMMABILITY - The FAR 25 Bunsen burner test should be a continued requirement but the test should be modified to give more valid results for materials that drip and melt away from the flame. The ASTM committee-07 Flammability of Aerospace Materials accepted the task of modifying this test as required.

SHORT TERM (Cont'd)

SMOKE - The NBS smoke chamber should be standardized at the 2.5 watts/ sq. cm. irradiant level in the flaming condition and retained as a requirement for screening aircraft interior materials.

ASTM E-162 RADIANT PANEL TEST - This test should not be considered for short term rulemaking.

NBS FLOORING RADIANT PANEL TEST - A specialized test for floor covering is not required and should not be considered further.

Enclosure 1

MEMBERS OF SAFE SUBCOMMITTEE FOR MATERIALS EVALUATION & TEST

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Henri P. Branting

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Enclosure 2

AGENDA FOR MEETING OF

MATERIALS EVALUATION AND TESTING SUB-COMMITTEE

AMES RESEARCH CENTER

BLDG. 223, ROOM 100

AUGUST 16, 1979

8:30 a.m. I. ORGANIZATION AND SUBCOMMITTEE TASKS - R. W. BRICKER

8:40 a.m. II. BACKGROUND

A. REVIEW FAA 1977 HEARING CONCLUSIONS AS BASIS FOR SAFER AND INDUSTRY NEEDS - R. J. SUTTON - 30 min.

B. REVIEW FAR 25.853, 25,855, 25.139 AND FAA OBJECTIVES AND NEEDS IN A NEW ROLE - HENRI BRANTING - 30 min.

9:40 a.m. III. RECOMMENDED SUBCOMMITTEE APPROACH - R. W. BRICKER

10:00 a.m. IV. ESTABLISH TEST/STANDARD OBJECTIVES AND CLASSIFY ACCORDING TO IMPORTANCE - COMMITTEE

12:00 NOON LUNCH

1:00 p.m. V. TEST REVIEW

BUNSEN BURNER (FAR 25.853) - GUS SARKOS - 10 min.

LIMITING OXYGEN INDEX AND THERMO GRAVIMETRIC ANALYSIS - R. W. BRICKER - 10 min.

REVIEW OF NBS SMOKE CHAMBER - V. BABRAUSKAS - 10 min.

OSU RELEASE RATE CALORIMETER - DR. ED SMITH - 10 min.

RADIANT PANEL (ASTM E162-67) AND BOEING MODIFIED OSU - E. V. TUSTIN - 20 min.

DAC MODIFIED OSU - R. J. SUTTON - 10 min.

LAB TEST VALUE FOR MATH MODELING - DR. C. MacARTHUR - 10 min.

2:20 p.m.	VI.	EVALUATE EXISTING AND MODIFIED TESTS AGAINST THE TEST OBJECTIVES - COMMITTEE
3:00 p.m.	VII.	AGREE ON SUBCOMMITTEE OVERALL OBJECTIVES TO SATISFY FAA AND INDUSTRY NEEDS - COMMITTEE
3:30 p.m.	VIII.	CURRENT PROPOSAL STATUS
		FAA PROPOSED INTERIM STANDARD - G. SARKOS
		PROPOSAL FOR A CRASH FIRE SCENARIO - E. V. TUSTIN
		DESCRIBE THE CHI PROGRAM - R. J. SUTTON
4:30 p.m.	IX.	CRITIQUE THE PROPOSALS AND RELATE TO END ITEM NEEDS - COMMITTEE
5:00 p.m.	ADJOURN	

AUGUST 17, 1979

8:30 a.m.	X.	DEVELOP MORNING AGENDA BASED ON PREVIOUS DAYS RESULTS - COMMITTEE
8:45 a.m.	XI.	COVER PERTINENT ITEMS BASED ON DEVELOPED AGENDA
12:00 NOON	LUNCH	
1:00 p.m.	XII.	DEFINE WORK REQUIRING COMPLETION PRIOR TO SEPTEMBER 79 MEETING - COMMITTEE
		A. LAB TESTS
		B. TELEPHONE AND OTHER COORDINATION
2:00 p.m.	XIII.	PREPARE A LIST OF NEEDED R&D TO INCREASE OCCUPANT SURVIVABILITY - COMMITTEE
3:30 p.m.	XIV.	DEFINE ACTION ITEMS AND ASSIGNMENTS - R. W. BRICKER
5:00 p.m.	ADJOURN	

OBJECTIVES

In order to increase available passenger egress time

- Test methodology should relate to human hazard
- Results of tests should show material improvement with respect to fire hazard
- Results of tests when applied to material selection can be verified as used in full scale tests
- Test methodology should combine evaluation of flammability, smoke and gas products
- Test specimen should represent the end use item
- Materials rating system must be quantitative and reproducible
- Test technique should be reasonably available and low in cost
- Test method must be available by October 1, 1979

4

8-17-79
HCS

objectives	Weight	FAR CURRENT		FAR mod		NBS SMOKE CURRENT		NBS SMOKE mod.		ASTM 162		OSU		TGA/DSC		LOI		T-3	
①	10	3.6	36	4.6	46	4.6	46	5.8	58	5.6	56	9.1	91	3.3	33	3.2	32	3.5	35
②	10	6.9	69	5.1	51	5.1	51	6.6	66	5.9	59	9.0	90	3.8	38	3.4	34	4.9	49
③	10	3.3	33	4.3	43	4.3	43	5.7	57	5.0	50	8.5	85	2.6	26	2.4	24	4.4	44
④	8	1.0	8	1.7	14	3.2	26	4.5	36	4.6	37	8.2	66	2.1	17	1.3	10.4	2.3	18.4
⑤	9	5.9	53	5.9	53	5.8	52	6.1	55	7.6	68	8.1	73	1.1	10	0.9	8.1	6.8	61.2
⑥	8	6.9	55	8	64	7.1	57	6.4	51	6.6	53	7.2	58	6.6	53	7.4	59.2	5.1	40.8
⑦	7	9.8	69	7.8	55	8.4	59	5.4	38	8.2	57	4.8	34	5.3	37	8.1	56.7	3.5	24.5
Σ			323		326		334		361		380		497		214		224.4		273
⑧	Yes		7		2		9		1		9		3		3		9		3
	No		0		3		0		7		0		6		5		0		4

Enclosure 4

FIRE SAFETY EVALUATION

R. J. Sutton 9-10-7

Enclosure 5

25.XYX Safety Evaluation of Personnel Areas

(a) Interior Fire Hazard.

Those inhabited and pressurized volumes related to personnel safety from fire must be evaluated under the provisions of paragraphs (b) and (c) of this section.

(b) Fire Sources.

The interior must be shown by analysis, tests, or both, that consideration has been given to minimizing fire sources. In addition the following apply:

(1) The evaluation must include--

(i) The typical BTU loading expected in service;

(ii) Identification of principal elements that have been fire sources;

(iii) An analysis of the points identified in subdivision (i) and (ii) of this subparagraph and the steps taken to minimize them.

(c) Material Selection.

It must be shown by analysis, tests, or both, that fire safe state-of-the-art material have been selected for various locations in the aircraft interior. This will be demonstrated by responding to the following:

(1) A knowledge of commercially available materials will be maintained.

(2) Materials and assemblies will be qualified for flammability visibility and toxicity by tests approved by FAA.

(3) Material procured and tested to specifications that include a practical level of quality control fire testing for that particular material.

THE CONTRIBUTION OF CABIN SUPPLIES

AND

PASSENGER CARRY-ON ITEMS

TO A

POST-CRASH FUEL FED FIRE

SEPTEMBER, 1979

FOREWORD

This report summarizes the results of an analysis of materials contained within typical B-747 and L-1011-1 aircraft cabins. Primary emphasis is placed on those items brought on board the aircraft by passengers and cabin supplies boarded as a part of normal airline operation. The study was conducted July 1979 through August 1979 as an assigned task of the SAFER Interior Materials Short Term Action Sub-group.

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1.0 INTRODUCTION

This report is issued to publish the results of a study of materials contained within a typical aircraft passenger cabin at the time of a post-crash fuel-fed fire condition. The primary objective was to determine if cabin supplies and carry-on items are significant contributors to such a fire. Although this report primarily deals with wide-body aircraft, the findings are relevant to narrow-body equipment since cabin supplies and carry-on items are directly comparable. The primary difference is in terms of fewer square feet of material in all categories on narrow-body aircraft.

2.0 SUMMARY

Cabin interior furnishings represent the largest area of potential fuel sources in a post-crash-fuel-fed fire condition. However, these items conform to the rigid fire retardency requirements of FAR 25.853. The next largest fuel source is passenger clothing. These materials are capable of supporting combustion and could be contributors. Passenger carry-on items and cabin supplies represent the smallest potential fuel source. Many of these items meet the fire retardency requirements of FAR 25.853 or are protected in FAR 25.853 stowage compartments. The study shows these materials are not major contributors, however, some items were identified as being fuel sources.

3.0 BASIS OF STUDY

3.1 All data is based on a Lockheed L-1011-1 and Boeing B-747 aircraft configured as shown in Appendix i.

3.2 Two hypothetical crash conditions were evaluated; Condition A - Take-Off Mode and Condition B - Landing Mode.

3.3 All burn rates for materials based on the standards published in FAR 25.853. See Appendix ii.

3.4 Combustibility of cabin supplies and carry-on items is based on area (square feet) to allow direct comparison with cabin interior materials conforming to FAR 25.853. See Appendix ii.

3.5 Cabin interior materials area (sq.ft.) determined from evaluation of typical L-1011-1 and B-747 aircraft. See Tables III and IV.

3.6 Cabin supplies area (sq. ft.) determined from requirements for typical airline loading of alcoholic beverages and cabin supplies. See Tables V and VI.

3.0 BASIS OF STUDY (continued)

3.7 Carry-on items area (sq. ft.) determined from typical airline acceptance standards and observation study of typical passengers boarding aircraft. See Tables VII, VIII and Appendix v.

3.8 Data on passenger clothing is confined to outer garments only. Quantity and types of outer garments is derived from observation study of typical passengers. Flammability characteristics of outer garments is derived from the Code of Federal Regulations, Title 16. See Tables IX, X, and Appendix iv.

3.9 Protection of non-FAR 25.853 materials by FAR 25.853 stowage compartments is considered a reasonable technical assumption. Many non-FAR 25.853 materials are required to be stowed in FAR 25.853 compartments. However, allowances are made for dislodgement of such materials under Crash Condition B. See Tables V, VI, VII, and VIII.

3.10 Exposure of materials to flame is considered to be less than 2 minutes based on FAR 121.291 which requires demonstrated evacuation of passengers within 90 seconds. See Appendix iii.

4.0 CRASH CONDITION A - L-1011-1

4.1 Aircraft Status

- Take-off Flight Mode
- Landing Gear Retracted
- Fuselage Upright and Unbroken
- Exits Open and Evacuation Slides Deployed
- Fuel Fed Fire in Progress
- Survivable Crash - Mild Impact
- Adequate Time for Evacuation of Survivors

4.2 Cabin Supply Status

- All Supplies Stowed in Designated Compartments, Fixed or Restrained
- All Stowage Compartments Intact
- See Tables I and V

4.3 Carry-On Items Status

- All Carry-On Items in Stowed Position
- See Tables I and VII

4.4 Passenger Status

- Maximum Payload - 293 Passengers
- See Tables I and IX

4.5 Total Available Material

The total material in the cabin is calculated to be 30,672 square feet. The total is distributed as follows:

	Total	Available as Fuel
Cabin Interior	18,589 (61%)	0
Passenger Clothing	6,087 (20%)	6,087 (20%)
Carry-on Items	3,780 (12%)	916 (3%)
Cabin Supplies	2,216 (7%)	47 (0%)
TOTAL	30,672 Sq.Ft.	7,050 Sq.Ft. (23%)

See Tables I, III, V, VII, and IX.

5.0 CRASH CONDITION B - L-1011-1

5.1 Aircraft Status

- Landing Flight Mode
- Landing Gear Retracted, Collapsed, or Sheared Off
- Fuselage Upright but Broken Forward of Wing Leading Edge - Forward of Emergency Exit, Left Side
- Exits Open and Evacuation Slides Deployed
- Fuel Fed Fire in Progress Left Hand Side
- 10% of Cabin Subjected to Fire through Break in Fuselage
- Survivable Crash - Moderate Impact
- Adequate Time for Evacuation of Survivors

5.2 Cabin Supply Status

- 25% of Stowed Items Dislocated on Impact
- See Tables I and V

5.3 Carry-on Item Status

- 10% of Stowed Items Dislocated on Impact
- See Tables I and VII

5.4 Passenger Status

- Maximum Payload - 293 Passengers
- See Tables I and IX

5.5 Total Available Material

The total material in the cabin is calculated to be [illegible] square feet. The total is distributed as follows:

	Total	Available [illegible] Exit
Cabin Interior	18,589 ([illegible])	[illegible]
Passenger Clothing	6,087 ([illegible])	[illegible]
Carry-on Items	3,780 ([illegible])	[illegible]
Cabin Supplies	2,216 ([illegible])	[illegible]
TOTALS	30,672 Sq.Ft.	[illegible]

See Tables I, III, V, VII, and IX.

6.0 CRASH CONDITION A - B-747

6.1 Aircraft Status

- Take-off Flight Mode
- Landing Gear Retracted
- Fuselage Upright and Unbroken
- Exits Open and Evacuation Slides Deployed
- Fuel Fed Fire in Progress
- Survivable Crash - Mild Impact
- Adequate Time for Evacuation of Survivors

6.2 Cabin Supply Status

- All Supplies Stowed in Designated Compartments, Bins, or Racks
- All Stowage Compartments Intact
- See Tables II and VI

6.3 Carry-on Item Status

- All Carry-on Items in Stowed Position
- See Tables II and VIII

6.4 Passenger Status

- Maximum Payload - Passengers
- See Tables II and X

6.5 Total Available Material

The total material in the cabin is calculated to be 49,277 square feet. The total is distributed as follows:

	Total	Available as Fuel
Cabin Interior	26,857 (55%)	0
Passenger Clothing	8,980 (18%)	8,980 (18%)
Carry-on Items	3,940 (8%)	2,588 (5%)
Cabin Supplies	9,500 (19%)	2,006 (4%)
TOTALS	49,277 Sq.Ft.	13,574 Sq.Ft. (27%)

See Tables II, IV, VI, VIII, and X.

7.0 CRASH CONDITION B - B-747

7.1 Aircraft Status

- Landing Flight Mode
- Landing Gear Retracted, Collapsed, or Sheared Off
- Fuselage Upright but Broken Forward of Wing Leading Edge - Forward of Emergency Exit, Left Side
- Exits Open and Evacuation Slides Deployed
- Fuel Fed Fire in Progress Left Hand Side
- 10% of Cabin Subjected to Fire through Break in Fuselage
- Survivable Crash - Moderate Impact
- Adequate Time for Evacuation of Survivors

7.2 Cabin Supply Status

- 25% of Stowed Items Dislocated on Impact
- See Tables II and VI

7.3 Carry-on Item Status

- 10% of Stowed Items Dislocated on Impact
- See Tables II and VIII

7.4 Passenger Status

- Maximum Payload - Passengers
- See Tables II and X

7.5 Total Available Material

The total material in the cabin is calculated to be 49,277 square feet. The total is distributed as follows:

	Total	Available as Fuel
Cabin Interior	26,857 (55%)	0
Passenger Clothing	8,980 (18%)	8,980 (18%)
Carry-on Items	3,940 (8%)	2,588 (5%)
Cabin Supplies	9,500 (19%)	3,233 (7%)
TOTAL	49,277 Sq.Ft.	14,801 Sq.Ft. (30%)

See Tables II, IV, VI, VIII, and X.

8.0 CONCLUSIONS - L-1011-1

8.1 The total amount of material of all types existing in the cabin is calculated to be 30,672 square feet. Of this total, materials of all types capable of supporting combustion as defined in FAR 25.853 amount to 7,050 square feet (23.2%) in Crash Condition A and 7,444 square feet (24.4%) in Crash Condition B. See Table I.

8.2 In both Crash Conditions A and B, the most significant category of combustible materials is passenger clothing. A total of 6,087 square feet (20%) is available. See Table I.

8.3 Carry-on items capable of supporting combustion amount to 916 square feet (3%) in Crash Condition A and 1,112 square feet (3.6%) in Crash Condition B. Major contributors in both conditions are plastic or paper shopping (tote) bags and ladies handbags. See Tables I and VII.

8.4 Cabin supplies capable of supporting combustion amount to 47 square feet (0.2%) in Crash Condition A and 245 square feet (0.8%) in Crash Condition B. Based on these figures, cabin supplies are not considered major contributors. See Table I.

8.5 Stowage of non-FAR 25.853 carry-on items and cabin supplies in FAR 25.853 compartments reduces the amount of combustible material available in these categories from 3,718 square feet to 963 square feet (74% reduction) in Crash Condition A. In Crash Condition B, 394 square feet of stowed material is dislodged, and the reduction is from 3,718 square feet to 1,357 square feet (64%). These findings confirm the contribution of present FAR 25.853 stowage to post-crash safety. See Table I.

9.0 CONCLUSIONS - B-747

9.1 The total amount of material of all types existing in the cabin is calculated to be 49,277 square feet. Of this total, materials of all types capable of supporting combustion as defined in FAR 25.853 amount to 13,574 square feet (27%) in Crash Condition A and 14,801 square feet (30%) in Crash Condition B.

9.2 In both Crash Conditions A and B, the most significant category of combustible materials is passenger clothing. A total of 8,980 square feet (18%) is available. See Table II.

9.3 Carry-on items capable of supporting combustion amount to 2,588 square feet (5%) in both Crash Condition A and Crash Condition B.

See Tables II and VIII.

9.4 Cabin supplies capable of supporting combustion amount to 2,006 square feet (4%) in Crash Condition A and 3,233 square feet (7%) in Crash Condition B. Pillows and blankets made of Non-FAR 25.853 materials comprise the majority of this category. See Tables II and VI.

9.5 The amount of carry-on items and cabin supply materials available as fuel could be significantly reduced if more FAR 25.853 stowage provisions were available. This is especially true with regard to overhead stowage compartments. On the B-747 these compartments are constructed of FAR 25.853 materials which provides a degree of protection, however, they are not complete closures in that mesh type netting is used in lieu of solid panels in many applications. For the purpose of this study, these compartments were not considered protected areas.

10.0 RECOMMENDATIONS

10.1 Short Term

The FAA should issue an advisory circular to Air Carrier Operators indicating the degree that passenger service and carry-on items, which are currently not included in FAR 25.853, contribute to fire fuel. This advisory circular should encourage Operators to:

- Review and establish procedures which would minimize the quantity of air carrier supplied items in this category which are available to passengers during take-off and landing.

- Establish flight attendant training programs and procedures to promote awareness and identification of flammable tote type carry-on items so that when possible, these items could receive preferential priority of storage in FAR 25.853 protected compartments.

10.2 Long Term

The FAA should investigate the feasibility of rule making to:

- Require that coatrooms and stowage compartments intended for passenger carry-on items be enclosed with FAR 25.853 panels or solid doors to improve fire protection.

- Require that pillows and blankets meet FAR 25.853.

TABLE I - RECAP OF ALL MATERIALS AVAILABLE AS POTENTIAL FUEL - L-1011-1

Materials	Total Area (Sq.Ft.)	FAR 25.853 Compliance Status		Stowage Influence Non FAR 25.853 Mat'l in FAR 25.853 Approved Compartments		Area of Material Dislocated From FAR 25.853 Stowage		Total Area of Non FAR 25.853 Material Available	
		Area Pass (Sq.Ft.)	Area Fail (Sq.Ft.)	Area Protected (Sq.Ft.)	Area Un-Protected (Sq.Ft.)	Condition A (Sq.Ft.)	Condition B (Sq.Ft.)	Condition A (Sq.Ft.)	Condition B (Sq.Ft.)
Cabin Interior (See Table II)	18,589 (61%)	18,589	0	N/A	N/A	N/A	N/A	0	0
Cabin Supplies (See Table III)	2,216 (7%)	1,378	838	791	47	0	198	47	245
Passenger Carry-on Items (See Table IV)	3,780 (12%)	900	2,880	1,964	916	0	196	916	1,112
Passenger Clothing (See Table V)	6,087 (20%)	0	6,087	N/A	N/A	N/A	N/A	6,087	6,087
TOTALS	30,672	20,867 (68%)	9,805 (32%)	2,755	963	N/A	394	7,050 (23.2%)	7,444 (24.4%)

TABLE II - RECAP OF ALL MATERIALS AVAILABLE AS POTENTIAL FUEL - B-747

Materials	Total Area (Sq.Ft.)	FAR 25.853 Compliance Status		Stowage Influence Non FAR 25.853 Mat'l in FAR 25.853 Approved Compartments		Area of Material Dislocated From FAR 25.853 Stowage		Total Area of Non FAR 25.853 Material Available	
		Area Pass (Sq.Ft.)	Area Fail (Sq.Ft.)	Area Protected (Sq.Ft.)	Area Un-Protected (Sq.Ft.)	Condition A (Sq.Ft.)	Condition B (Sq.Ft.)	Condition A (Sq.Ft.)	Condition B (Sq.Ft.)
Cabin Interior (See Table IV)	26,857 (55%)	26,857	0	N/A	N/A	N/A	N/A	0	0
Cabin Supplies (See Table VI)	9,500 (19%)	2,585	6,915	4,909	2,006	0	1,227	2,006	3,233
Passenger Carry-on Items (See Table VIII)	3,940 (8%)	1,352	2,588	0	2,588	0	0	2,588	2,588
Passenger Clothing (See Table X)	8,980 (18%)	0	8,980	N/A	N/A	N/A	N/A	8,980	8,980
TOTALS	49,277	30,794 (62%)	18,483 (38%)	4,909	4,594	N/A	1,227	13,574 (27%)	14,801 (30%)

TABLE III - L-1011-1 CABIN INTERIOR ANALYSIS

Cabin Materials (1)	FAR 25.853 Test Criteria	FAR 25.853 Status (2)	Total Surface Area (Square Feet)
1. Seats and Upholstery	25.853B - 12 Sec. Vertical	Passes	7,047
2. Partitions and Coverings	25.853A - 60 Sec. Vertical	Passes	790
3. Ceiling and Covering	25.853A - 60 Sec. Vertical	Passes	2,168
4. Sidewall and Covering	25.853A - 60 Sec. Vertical	Passes	2,488
5. Floor Panels	25.853A - 60 Sec. Vertical	Passes	2,506
6. Floor Covering	25.853B - 12 Sec. Vertical	Passes	2,506
7. Overhead Stowage Compartments	25.853A - 60 Sec. Vertical	Passes	1,084
			18,589

NOTES: (1) Based on typical L-1011-1 Aircraft.

(2) Based on review of all materials as certificated.

TABLE IV - B-747 CABIN INTERIOR ANALYSIS

Cabin Materials (1)	FAR 25.853 Test Criteria	FAR 25.853 Status (2)	Total Surface Area (Square Feet)
1. Seats and Upholstery	25.853B - 12 Sec. Vertical	Passes	10,179
2. Partitions and Coverings	25.853A - 60 Sec. Vertical	Passes	1,128
3. Ceiling and Covering	25.853A - 60 Sec. Vertical	Passes	3,142
4. Sidewall and Covering	25.853A - 60 Sec. Vertical	Passes	3,599
5. Floor Panels	25.853A - 60 Sec. Vertical	Passes	3,626
6. Floor Covering	25.853B - 12 Sec. Vertical	Passes	3,626
7. Overhead Stowage Compartments	25.853A - 60 Sec. Vertical	Passes	1,557
			26,857

NOTES: (1) Based on typical B-747 aircraft.

(2) Based on review of all materials as certificated.

TABLE V - L-1011-1 CABIN SUPPLY ANALYSIS

Cabin Supply Items	Stowage Location	Stowage Compartment Influence FAR 25.853 Status	FAR 25.853 Stowed Item Status	Total Surface Area (Square Feet)
1. Pillows and Cases	Overhead compartments	Protected	Passes	675
2. Blankets	Overhead compartments	Protected	Passes	328
3. Flight Attendant Kits	Service Center Compartment	Protected	Passes	23
4. Stereo Headsets	Service Center Compartment	Protected	Passes	41
5. Coffee & Condiments	Service Center Compartment	Protected	Passes	31
6. Soft Drinks & Liquor	Service Ctr. Comp. & Carts	Protected	Passes	252
7. Champagne & Beer	Galley Compartments	Protected	Passes	28
8. Magazines	Magazine Racks - Cabin	Not protected	Fails	35
9. Flight Schedules	Schedule Holders - Cabin	Not protected	Fails	12
10. Literature, sickness bags, etc.	Passenger Seat Pockets	Protected	* Fails	365
11. Paper napkins, tissue, etc.	Lavatory & Svc. Ctr. Compartment	Protected	* Fails	170
12. Plastic Cups, Glasses, Stirrers, etc.	Service Center Compartments	Protected	* Fails	100
13. Cloth napkins, towels, etc.	Service Center Compartments	Protected	* Fails	40
14. Magazines	Service Center Compartments	Protected	* Fails	100
15. Peanuts - boxed	Service Center Compartments	Protected	* Fails	7
16. Cream and sugar	Service Center Compartments	Protected	* Fails	9
			TOTAL	2,216

NOTE: Data based on review of supplies boarded, quantities, and stowage locations as specified in Typical Loading-Alcoholic Beverages and Typical Loading-Cabin Supplies.

* Although material does not meet FAR 25.853 it is stowed in protected compartment.

TABLE VI - B-747 CABIN SUPPLY ANALYSIS

Cabin Supply Items	Stowage Location	Stowage Compartment Influence FAR 25.853 Status	FAR 25.853 Stowed Item Status	Total Surface Area (Square Feet)
1. Pillows and Cases	Overhead compartments	Not protected	Fails	987
2. Blankets	Overhead compartments	Not protected	Fails	754
3. Flight Attendant Kits	Cabin Behind Seats	Not protected	Fails	35
4. Stereo Headsets	Coatrooms 2 & 3	Protected	* Fails	62
5. Coffee & Condiments	Galley compartments	Protected	* Fails	47
6. Soft Drinks & Liquor	Galley compartments	Protected	* Fails	378
7. Champagne & Beer	Galley Compartments	Protected	* Fails	42
8. Magazines	Magazine Racks - Cabin	Protected	* Fails	203
9. Literature, sickness bags, etc.	Passenger Seat Pockets	Protected	* Fails	548
10. Paper napkins, tissue, etc.	Lavatories	Protected	* Fails	255
11. Plastic Cups, Glasses, Stirrers, etc.	Galley Compartments	Protected	* Fails	150
12. Cloth napkins, towels, etc.	Galley Compartments	Protected	* Fails	60
13. Newspapers	Passed out to psgrs. before flt.	Not protected	Fails	230
14. Meal Trays and meal related goods	Galley Compartments	Protected	* Fails	3,164
15. Carts, Tray Carriers,etc.	Galley Compartments	Protected	Passes	2,585
			TOTAL	9,500

NOTE: Data based on review of supplies boarded, quantities, and stowage locations as specified in Typical Loading-Alcoholic Beverages and Typical Loading-Cabin Supplies. See Appendix v and vi.

* Although material does not meet FAR 25.853, it is stowed in protected compartments.

TABLE VII - L-1011-1 CARRY-ON ITEM ANALYSIS

Carry-on Items (1)	Qty. (1)	Stowage Location (2)	Stowage Influence FAR 25.853 Status	FAR 25.853 Stowed Item Status	Total Surface Area (Square Feet)
1. Brief & Attache Cases	31	Under Passenger Seat	N/A	Passes	270
2. Luggage, Soft Side	38	Under Passenger Seat	N/A	Passes	330
3. Luggage, Straw	2	Under Passenger Seat	N/A	Passes	17
4. Garment Bags	14	Coatrooms	N/A	Passes	196
5. Cameras with Cases	12	Under Passenger Seat	N/A	Passes	31
6. Infant Bags	2	Under Passenger Seat	N/A	Passes	17
7. Cosmetic Cases	4	Under Passenger Seat	N/A	Passes	39
8. Cardboard Boxes	4	Under Passenger Seat	(2)	Fails	35
9. Plastic Bags	42	Under Passenger Seat	(2)	Fails	365
10. Cloth Bags	4	Under Passenger Seat	(2)	Fails	35
11. Tennis Racquets	6	Under Passenger Seat	(2)	Fails	12
12. Purses	110	Under Passenger Seat	(2)	Fails	440
13. Crib	2	Passenger Seat	(2)	Fails	17
14. Books & Magazines	4	Passenger Seat	(2)	Fails	8
15. Prosthetic (Walking Canes)	2	Floor - Sidewall Area	(2)	Fails	4
16. Top Coats	10	Coatrooms	Protected	Fails	140
17. Sweaters, Jackets, misc.	112	Overhead Stowage Bins	Protected	Fails	1,824
				TOTAL	3,780

NOTE: (1) Determined from observation study of typical passengers boarding L-1011-1 aircraft.

(2) Partially protected by FAR 25.853 cabin materials but for purposes of this study are considered not protected.

TABLE VIII - B-74. CARRY-ON ITEM ANALYSIS

Carry-on Items (1)	Qty. (1)	Stowage Location (2)	Stowage Influence FAR 25.853 Status	FAR 25.853 Stowed Item Status	Total Surface Area (Square Feet)
1. Brief & Attache Cases	45	Under Passenger Seat	N/A	Passes	405
2. Luggage, Soft Side	56	Under Passenger Seat	N/A	Passes	495
3. Luggage, Straw	4	Under Passenger Seat	N/A	Passes	26
4. Cameras with Cases	18	Under Passenger Seat	N/A	Passes	47
5. Infant Bags	3	Under Passenger Seat	N/A	Passes	26
6. Cosmetic Cases	6	Under Passenger Seat	N/A	Passes	59
7. Cardboard Boxes	6	Under Passenger Seat	(2)	Fails	53
8. Plastic Bags	63	Under Passenger Seat	(2)	Fails	548
9. Cloth Bags	6	Under Passenger Seat	(2)	Fails	53
10. Tennis Racquets	9	Under Passenger Seat	(2)	Fails	18
11. Purses	165	Under Passenger Seat	(2)	Fails	660
12. Crib	3	Passenger Seat	(2)	Fails	26
13. Books & Magazines	6	Passenger Seat	(2)	Fails	12
14. Garment Bags	21	Coat rooms	N/A	Passes	294
15. Top Coats	15	Coat rooms	(2)	Fails	210
16. Sweaters, Jackets, misc.	168	Overhead Stowage Bins	(2)	Fails	1,008
				TOTAL	3,940

NOTE: (1) Determined from observation study of typical passenger boarding B-747 aircraft.

(2) Partially protected by FAR 25.853 cabin materials but for purposes of this study are considered not protected.

TABLE IX - L-1011-1 PASSENGER CLOTHING ANALYSIS

Passenger Types	Passenger Distribution By Type (1)	Passenger Outer-Garment Area (2) (Square Feet)	FAR 25.853 Status (3)	Total Surface Area (Square Feet)
1. Adult Male	112	23.0	Fails	2,576
2. Adult Female	144	20.9	Fails	3,010
3. Children	27	16.5	Fails	446
4. Infants	10	5.5	Fails	55
				6,087

NOTES: (1) Determined from observation study of typical passengers boarding L-1011-1 aircraft.

(2) Calculated as follows:
Avg. Adult Male: Business Suit or Coat/Slacks Combination, Shirt, and Socks = 23.0 sq. ft.
Avg. Adult Female: Pant Suit or Skirt/Blouse Combination, hosiery = 20.9 sq. ft.
Avg. Child: Calculated as 75% of Adult Male - Female Avg. (21.95 sq. ft.) = 16.5 sq. ft.
Avg. Infant: Calculated as 25% of Adult Male - Female Avg. (21.95 sq. ft.) = 5.5 sq. ft.

(3) Determined from Standard on Clothing Flammability, Code of Federal Regulations, Title 16. See Appendix IV.

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SPECIAL AVIATION FIRE AND EXPLOSION REDUCTION (SAFER) ADVISORY --ETC(U)
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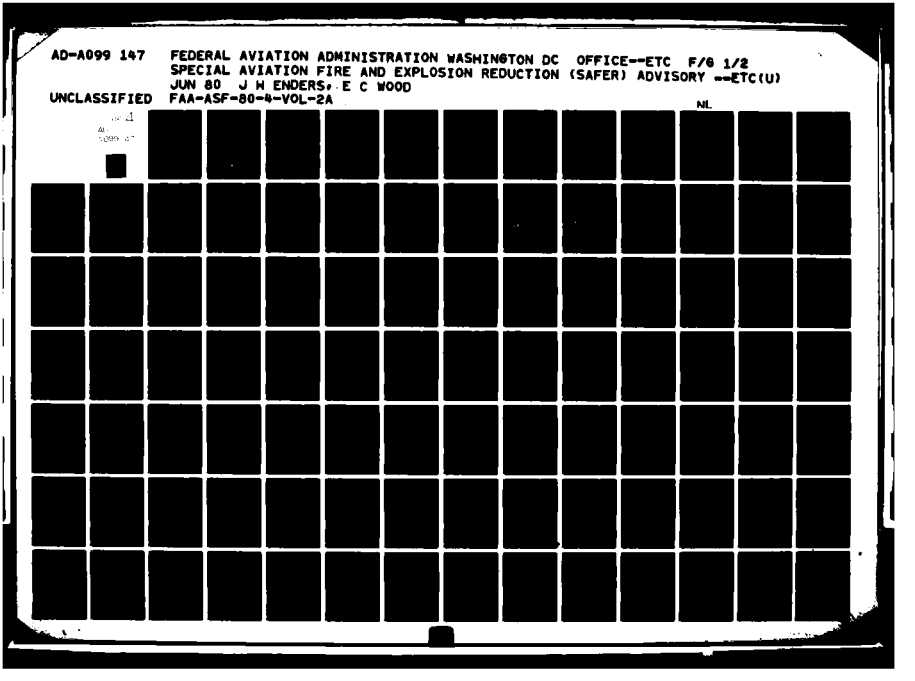


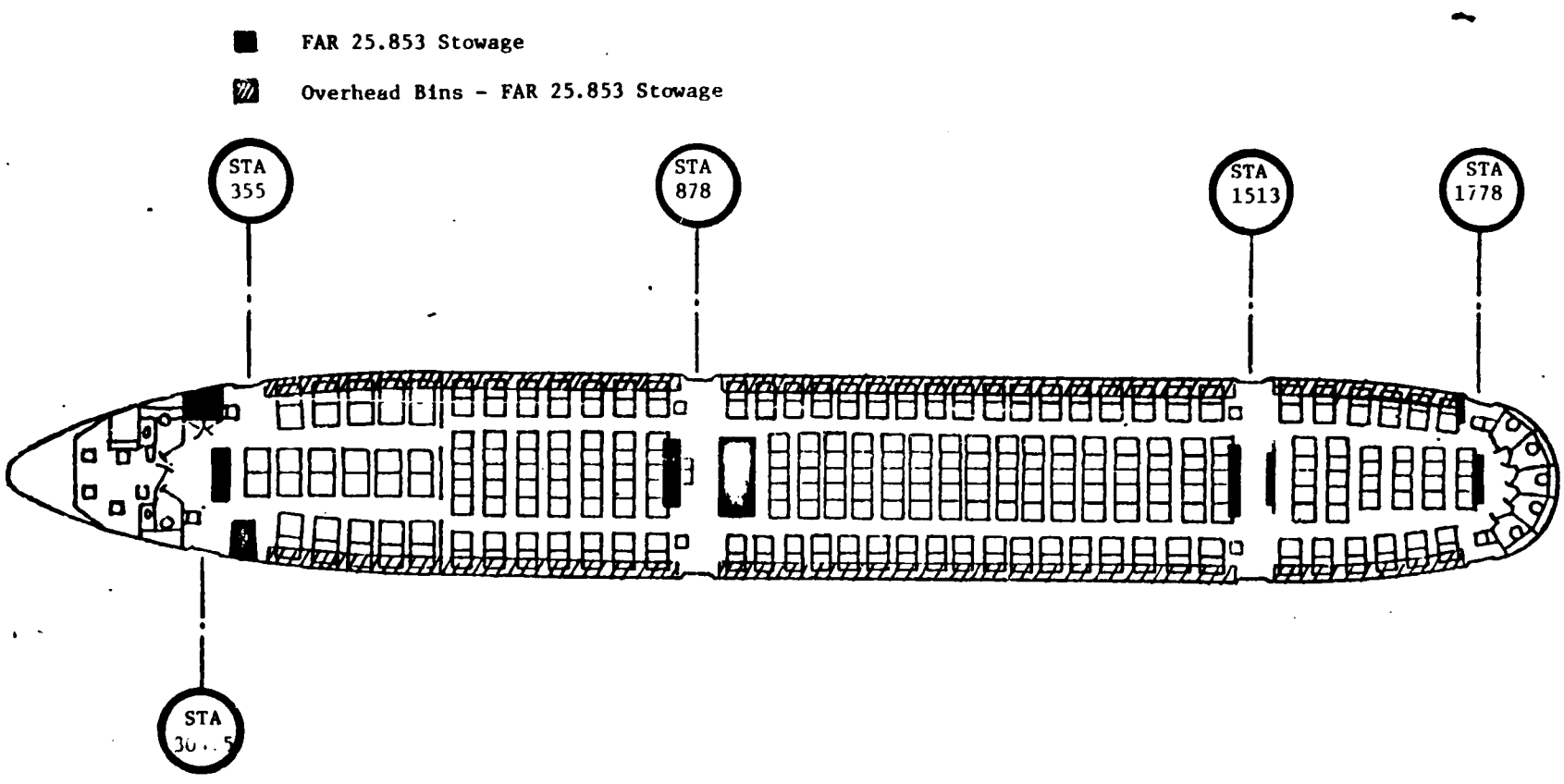
TABLE X - B-747 PASSENGER CLOTHING ANALYSIS

Passenger Types	Passenger Distribution By Type (1)	Passenger Outer-Garment Area (2) (Square Feet)	FAR 25.853 Status (3)	Total Surface Area (Square Feet)
1. Adult Male	185	23.0	Fails	4,255
2. Adult Female	196	20.9	Fails	4,097
3. Children	33	16.5	Fails	545
4. Infants	15	5.5	Fails	0
				8,980

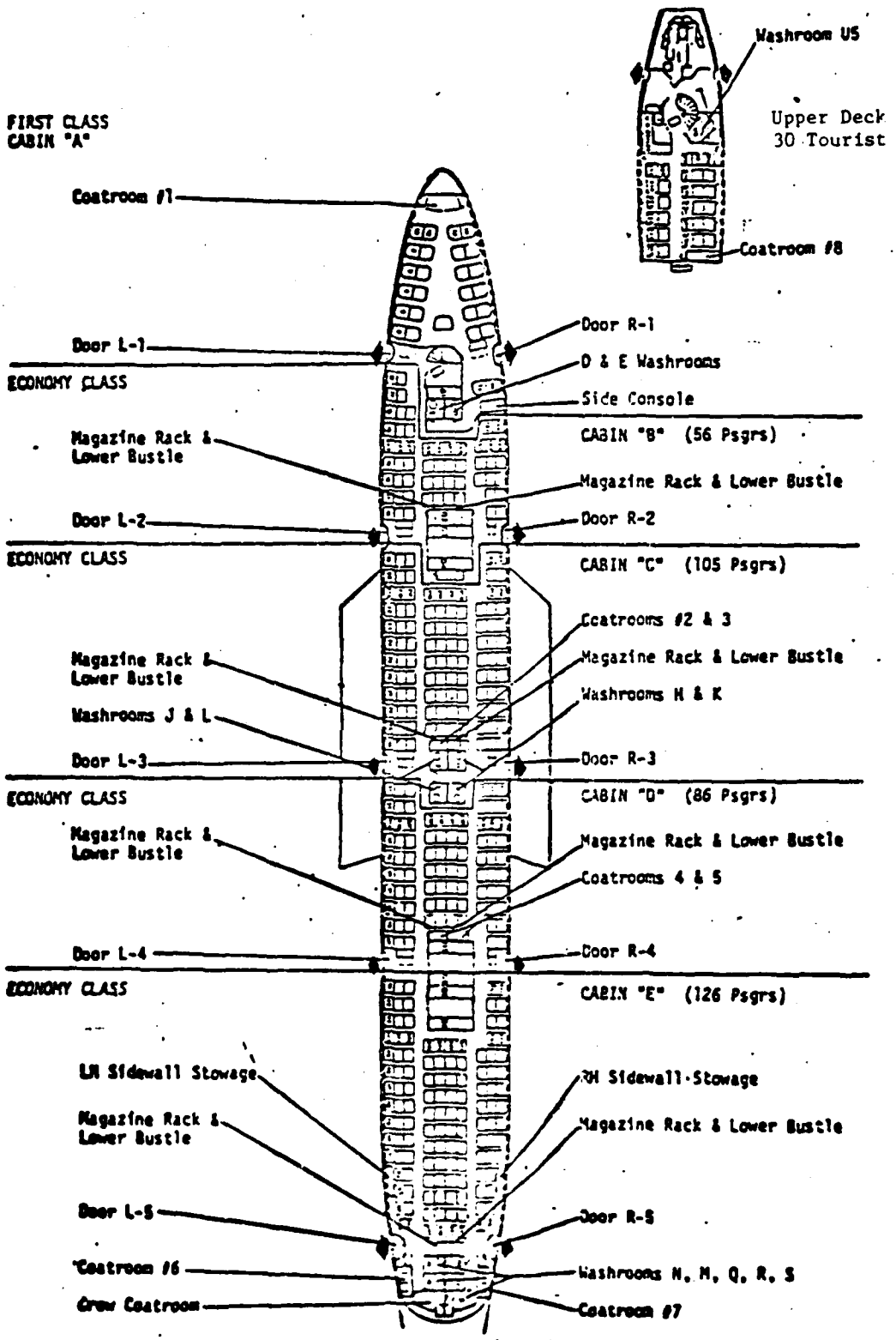
NOTES: (1) Determined from observation study of typical passengers boarding B-747.

(2) Calculated as follows:
Avg. Adult Male: Business Suit or Coat/Slacks Combination, Shirt, and Socks = 23.0 sq. ft.
Avg. Adult Female: Pant Suit or Skirt/Blouse Combination, hosiery = 20.9 sq. ft.
Avg. Child: Calculated as 75% of Adult Male - Female Avg. (21.95 sq. ft.) = 16.5 sq. ft.
Avg. Infant: Calculated as 25% of Adult Male - Female Avg. (21.95 sq. ft.) = 5.5 sq. ft.

(3) Determined from Standard on Clothing Flammability, Code of Federal Regulations, Title 16. See Appendix iv.



L-1011-1
293 PASSENGER CONFIGURATION
32 FIRST CLASS/261 TOURIST



B-747
429 Passenger Configuration
26 First Class/403 Tourist

propriate warning markings on the cabin pressure differential indicator meet the warning requirement for pressure differential limits and an aural or visual signal (in addition to cabin altitude indicating means) meets the warning requirement for cabin pressure altitude limits if it warns the flight crew when the cabin pressure altitude exceeds 10,000 feet.

(7) A warning placard at the pilot or flight engineer station if the structure is not designed for pressure differentials up to the maximum relief valve setting in combination with landing loads.

(8) The pressure sensors necessary to meet the requirements of paragraphs (b)(5) and (b)(6) of this section and § 25.1447(c), must be located and the sensing system designed so that, in the event of loss of cabin pressure in any passenger or crew compartment (including upper and lower lobe galleys), the warning and automatic presentation devices, required by those provisions, will be actuated without any delay that would significantly increase the hazards resulting from decompression.

§ 25.843 Tests for pressurized cabins.

(a) *Strength test.* The complete pressurized cabin, including doors, windows, and valves, must be tested as a pressure vessel for the pressure differential specified in § 25.365(d).

(b) *Functional tests.* The following functional tests must be performed:

(1) Tests of the functioning and capacity of the positive and negative pressure differential valves, and of the emergency release valve, to simulate the effects of closed regulator valves.

(2) Tests of the pressurization system to show proper functioning under each possible condition of pressure, temperature, and moisture, up to the maximum altitude for which certification is requested.

(3) Flight tests, to show the performance of the pressure supply, pressure and flow regulators, indicators, and warning signals, in steady and stepped climbs and descents at rates corresponding to the maximum attainable within the operating limitations of the airplane, up to the maximum altitude for which certification is requested.

(4) Tests of each door and emergency exit, to show that they operate properly after being subjected to the flight tests prescribed in subparagraph (3) of this paragraph.

FIRE PROTECTION

§ 25.851 Fire extinguishers.

(a) *Hand fire extinguishers.* For hand fire extinguishers the following apply:

(1) Each hand fire extinguisher must be approved.

(2) The types and quantities of each extinguishing agent used must be appropriate to the kinds of fires likely to occur where used.

(3) Each extinguisher for use in a personnel compartmet must be designed to minimize the hazard of toxic gas concentrations.

(4) A readily accessible hand fire extinguisher must be available for use in each Class A or Class B cargo compartment.

(b) *Built-in fire extinguishers.* If a built-in fire extinguisher system is required—

(1) The capacity of each system, in relation to the volume of the compartment where used and the ventilation rate, must be adequate for any fire likely to occur in that compartment; and

(2) Each system must be installed so that—

(i) No extinguishing agent likely to enter personnel compartments will be hazardous to the occupants; and

(ii) No discharge of the extinguisher can cause structural damage.

§ 25.853 Compartment interiors.

Materials (including finishes or decorative surfaces applied to the materials) used in each compartment occupied by the crew or passengers must meet the following test criteria as applicable:

(a) Interior ceiling panels, interior wall panels, partitions, galley structure, large

cabinet walls, structural flooring, and materials used in the construction of stowage compartments (other than underseat stowage compartments and compartments for stowing small items such as magazines and maps) must be self-extinguishing when tested vertically in accordance with the applicable portions of Appendix F of this Part, or other approved equivalent methods. The average burn length may not exceed six inches and the average flame time after removal of the flame source may not exceed 15 seconds. Drippings from the test specimen many not continue to flame for more than an average of three seconds after falling.

(b) Floor covering, textiles (including draperies and upholstery), seat cushions, padding, decorative and non-decorative coated fabrics, leather, trays and galley furnishings, electrical conduit, thermal and acoustical insulation and insulation covering, air ducting, joint and edge covering, cargo compartment liners, insulation blankets, cargo covers, and transparencies, molded and thermoformed parts, air ducting joints, and trim strips (decorative and chafing), that are constructed of materials not covered in paragraph (b-2) of this section, must be self extinguishing when tested vertically in accordance with the applicable portions of Appendix F of this Part, or other approved equivalent methods. The average burn length may not exceed 8 inches and the average flame time after removal of the flame source may not exceed 15 seconds. Drippings from the test specimen may not continue to flame for more than an average of 5 seconds after falling.

Appendix F

An Acceptable Test Procedure for Showing Compliance with §§ 25.853, 25.855, and 25.1359

(a) *Conditioning.* Specimens must be conditioned to 70° F., plus or minus 5° and at 50 percent plus or minus 5 percent relative humidity until moisture equilibrium is reached or for 24 hours. Only one specimen at a time may be removed from the conditioning environment immediately before subjecting it to the flame.

(b) *Specimen configuration.* Except as provided for materials used in electrical wire and cable insulation and in small parts, materials must be tested either as a section cut from a fabricated part as installed in the airplane or as a specimen simulating a cut section, such as: a specimen cut from a flat sheet of the material or a model of the fabricated part. The specimen may be cut from any location in a fabricated part; however, fabricated units, such as sandwich panels, may not be separated for test. The specimen thickness must be no thicker than the minimum thickness to be qualified for use in the airplane, except that: (1) thick foam parts, such as seat cushions, must be tested in ½-inch thickness; (2) when showing compliance with § 25.853(b-3) for materials used in small parts that must be tested, the materials must be tested in no more than ⅛-inch thickness; (3) when showing compliance with § 25.1359(d) for materials used in electrical wire and cable insulation, the wire and cable specimens must be the same size as used in the airplane. In the case of fabrics, both the warp and fill direction of the weave must be tested to determine the most critical flammability condition: When performing the tests prescribed in paragraphs (d) through (e) of this Appendix, the specimen must be mounted in a metal frame so that; (1) in the vertical tests of paragraph (d), the two long edges and the upper edge are held securely; (2) in the horizontal test of paragraph (e), the two long edges and the edge away from the flame are held securely; (3) the exposed area of the specimen is at least 2 inches wide and 12 inches long, unless the actual size used in the airplane is smaller; and (4) the edge to which the burner flame is applied must not consist of the finished or protected edge of the specimen but must be representative of the actual cross-section of the material or part installed in the airplane. When performing the test prescribed in paragraph (f) of this Appendix, the specimen must be mounted in a metal frame so that all four edges are held securely and the exposed area of the specimen is at least 8 inches by 8 inches.

(c) *Apparatus.* Except as provided in paragraph (h) of this Appendix, tests must be conducted in a draft-free cabinet in accordance with Federal Test Method Standard 191 Method 5903 (revised Method 5902) for the vertical test, or Method 5906 for horizontal test (available from the General Services Administration, Business Service Center, Region 3, Seventh & D Streets, S.W., Washington, D.C., 20407) or other approved equivalent methods. Specimens which are too large for the cabinet must be tested in similar draft-free conditions.

(d) *Vertical test, in compliance with § 25.853(a) and (b).* A minimum of three specimens must be tested and the results averaged. For fabrics, the direction of weave corresponding to the most critical flammability conditions must be parallel to the longest dimension. Each specimen must be supported vertically. The specimen must be exposed to a Bunsen or Tirrill burner with a nominal ⅜-inch I.D. tube adjusted to give a flame of

1½ inches in height. The minimum flame temperature measured by a calibrated thermocouple pyrometer in the center of the flame must be 1550° F. The lower edge of the specimen must be three-fourths inch above the top edge of the burner. The flame must be applied to the center line of the lower edge of the specimen. For materials covered by § 25.853(a), the flame must be applied for 60 seconds and then removed. For materials covered by § 25.853(b), the flame must be applied for 12 seconds and then removed. Flame time, burn length, and flaming time of drippings, if any, must be recorded. The burn length determined in accordance with paragraph (g) of this Appendix must be measured to the nearest one-tenth inch.

(e) *Horizontal test in compliance with § 25.853(b-2) and (b-3).* A minimum of three specimens must be tested and the results averaged. Each specimen must be supported horizontally. The exposed surface when installed in the aircraft must be face down for the test. The specimen must be exposed to a Bunsen burner or Tirrill burner with a nominal three-eighths inch I.D. tube adjusted to give a flame of 1½ inches in height. The minimum flame temperature measured by a calibrated thermocouple pyrometer in the center of the flame must be 1550° F. The specimen must be positioned so that the edge being tested is three-fourths of an inch above the top of, and on the center line of, the burner. The flame must be applied for 15 seconds and then removed. A minimum of 10 inches of the specimen must be used for timing purposes, approximately 1½ inches must burn before the burning front reaches the timing zone, and the average burn rate must be recorded.

(f) *Forty-five degree test, in compliance with § 25.855(a-1).* A minimum of three specimens must be tested and the results averaged. The specimens must be supported at an angle of 45° to a horizontal surface. The exposed surface when installed in the aircraft must be face down for the test. The specimens must be exposed to a Bunsen or Tirrill burner with a nominal three-eighths inch I.D. tube adjusted to give a flame of 1½ inches in height. The minimum flame temperature measured by a calibrated thermocouple pyrometer in the center of the flame must 1550° F. Suitable precautions must be taken to avoid drafts. One-third of the flame must contact the material at the center of the specimen and must be applied for 30 seconds and then removed. Flame time, glow time, and whether the flame penetrates (passes through) the specimen must be recorded.

(g) *Sixty degree test in compliance with § 25.1359(d).* A minimum of three specimens of each wire specification (make and size) must be tested. The specimen of wire or cable (including insulation) must be placed at an angle of 60° with the horizontal in the cabinet specified in paragraph (c) of this Appendix with the cabinet door open during the test or must be placed within a chamber approximately 2 feet high x 1 foot x 1 foot, open at the top and at one vertical side (front), and which allows sufficient flow of air for complete combustion, but which is free from drafts. The specimen must be parallel to and approximately 6 inches from the front of the chamber. The lower end of the specimen must be held rigidly clamped. The upper end of the specimen must pass over a pulley or rod and must have an appropriate weight attached to it so that the specimen is held tautly throughout the flammability test. The test specimen span between lower clamp and upper pulley or rod must be 24 inches and must be marked 8 inches from the lower end to indicate the central point for flame application. A flame from a Bunsen or Tirrill burner must be applied for 30 seconds at the test mark. The burner must be mounted underneath the test mark on the specimen, perpendicular to the specimen and at an angle of 30° to the vertical plane of the specimen. The burner must have a nominal bore of ⅜ inch, and must be adjusted to provide a 3-inch high flame with an inner cone approximately one-third of the flame height. The minimum temperature of the hottest portion of the flame, as measured with a calibrated thermocouple pyrometer, may not be

less than 1750° F. The burner must be positioned so that the hottest portion of the flame is applied to the test mark on the wire. Flame time, burn length, and flaming time of drippings, if any, must be recorded. The burn length determined in accordance with paragraph (g) of this Appendix must be measured to the nearest $\frac{1}{10}$-inch. Breaking of the wire specimens is not considered a failure.

(h) *Burn length.* Burn length is the distance from the original edge to the farthest evidence of damage to the test specimen due to flame impingement, including areas of partial or complete consumption, charring, or embrittlement, but not including areas sooted, stained, warped, or discolored, nor areas where material has shrunk or melted away from the heat source.

"seat belt" sign, "no smoking" sign, or any required exit sign, unless an auxiliary sign or other approved means for proper notification of the passenger is provided.

(c) All cargo may be carried forward of the foremost seated passengers and carry-on baggage may be carried alongside the foremost seated passengers, if the cargo (including carry-on baggage) is carried either in approved bins as specified in paragraph (b) of this section, or in accordance with the following:

(1) It is properly secured by a safety belt or other tie down having enough strength to eliminate the possibility of shifting under all normally anticipated flight and ground conditions.

(2) It is packaged or covered in a manner to avoid possible injury to passengers.

(3) It does not impose any load on seats or the floor structure that exceeds the load limitation for those components.

(4) Its location does not restrict access to or use of any required emergency or regular exit, or of the aisle in the passenger compartment.

(5) Its location does not obscure any passenger's view of the "seat belt" sign, "no-smoking" sign, or required exit sign, unless an auxiliary sign or other approved means for proper notification of the passenger is provided.

§ 121.287 Carriage of cargo in cargo compartments.

When cargo is carried in cargo compartments that are designed to require the physical entry of a crewmember to extinguish any fire that may occur during flight, the cargo must be loaded so as to allow a crewmember to effectively reach all parts of the compartment with the contents of a hand fire extinguisher.

§ 1221.288 [Rescinded]

§ 121.289 Landing gear: aural warning device.

(a) Each large airplane must have a landing gear aural warning device that functions continuously under the following conditions:

(1) For airplanes with an established approach wing-flap position, whenever the wing flaps are extended beyond the maximum certificated approach climb configuration position in the Airplane Flight Manual and the landing gear is not fully extended and locked.

(2) For airplanes without an established approach climb wing-flap position, whenever the wing flaps are extended beyond the position at which landing gear extension is normally performed and the landing gear is not fully extended and locked.

(b) The warning system required by paragraph (a) of this section—

(1) May not have a manual shutoff;

(2) Must be in addition to the throttle-actuated device installed under the type certification airworthiness requirements; and

(3) May utilize any part of the throttle-actuated system including the aural warning device.

(c) The flap position sensing unit may be installed at any suitable place in the airplane.

(d) [Deleted]

§ 121.291 Demonstration of emergency evacuation procedures.

(a) [For airplanes that were not shown to be in compliance with § 25.803(c)(7)(i) of this chapter in effect on December 1, 1978, during type certification, each certificate holder must show, by actual demonstration conducted in accordance with paragraph (a) of Appendix D to this Part, that the emergency evacuation procedures for each type and model of airplane with a seating capacity of more than 44 passengers, that is used in its passenger-carrying operations, allow the evacuation of the full seating capacity, including crewmembers, in 90 seconds or less, in each of the following circumstances:

(1) A demonstration must be conducted upon the initial introduction of a type and model of airplane into passenger-carrying operations. However, the demonstration need not be repeated for any airplane type or model that has the same number and type of exits, the same cabin configuration, and the same emergency equipment, as any other airplane used by the certificate holder in successfully demonstrating emergency evacuation in compliance with this paragraph.

(2) A demonstration must be conducted—

(i) Upon increasing by more than 5 percent the passenger seating capacity for which successful demonstration has been conducted; or

(ii) Upon a major change in the passenger cabin interior configuration that will affect the emergency evacuation of passengers.

(b) Each certificate holder operating or proposing to operate one or more landplanes in extended overwater operations, or otherwise required to have certain equipment under § 121.339, must show, by a simulated ditching conducted in accordance with paragraph (b) of Appendix D to this Part, that it has the ability to efficiently carry out its ditching procedures.

[(c) For airplanes that were shown to be in compliance with § 25.803(c)(7)(i) of this chapter in effect on December 1, 1978, during type certification, the operator must show that its emergency evacuation procedures and the training provided its crewmembers with respect to those procedures will provide emergency evacuation results equivalent to those obtained under § 25.803(c) of this chapter during airplane type certification.]

Subpart K—Instrument and Equipment Requirements

§ 121.301 Applicability.

This subpart prescribes instrument and equipment requirements for all certificate holders.

§ 121.303 Airplane instruments and equipment.

(a) Unless otherwise specified, the instrument and equipment requirements of this subpart apply to all operations under this Part.

(b) Instruments and equipment required by §§ 121.305 through 121.359 must be approved and installed in accordance with the airworthiness requirements applicable to them.

(c) Each airspeed indicator must be calibrated in knots, and each airspeed limitation and item of related information in the Airplane Flight Manual and pertinent placards must be expressed in knots.

(d) Except as provided in § 121.627 (b) and (c), no person may take off any airplane unless the following instruments and equipment are in operable condition:

(1) Instruments and equipment required to comply with airworthiness requirements under which the airplane is type certificated and as required by §§ 121.213 through 121.283 and 121.289.

(2) Instruments and equipment specified in §§ 121.305 through 121.321 and 121.359 for all operations, and the instruments and equipment specified in §§ 121.323 through 121.351 for the kind of operation indicated, wherever these items are not already required by subparagraph (1) of this paragraph.

(3) After September 1, 1976, the instruments and equipment required by § 121.360, unless required earlier—

(i) In a plan issued to the certificate holder by the Administrator to obtain information on system reliability; or

(ii) In the certificate holder's operations specifications.

§ 121.305 Flight and navigational equipment.

No person may operate an airplane unless it is equipped with the following flight and navigational instruments and equipment:

(a) An airspeed indicating system with heated pitot tube or equivalent means for preventing malfunctioning due to icing.

(b) A sensitive altimeter.

(c) A sweep-second hand clock (or approved equivalent).

(d) A free-air temperature indicator.

(e) A gyroscopic bank and pitch indicator (artificial horizon).

(f) A gyroscopic rate-of-turn indicator combined with an integral slip-skid indicator (turn and bank indicator), except that only a slip-skid indicator is required when a third attitude instrument system usable through flight attitudes of 360° of pitch and roll is installed in accordance with paragraph (j) of this section.

(g) A gyroscopic direction indicator (directional gyro or equivalent).

(h) A magnetic compass.

(i) A vertical speed indicator (rate-of-climb indicator).

Appendix D

Criteria For Demonstration of Emergency Evacuation Procedures Under § 121.291

(a) *Aborted takeoff demonstration.*

(1) The demonstration must be conducted either during the dark of the night or during daylight with the dark of the night simulated. If the demonstration is conducted indoors during daylight hours, it must be conducted with each window covered and each door closed to minimize the daylight effect. Illumination on the floor or ground may be used, but it must be kept low and shielded against shining into the airplane's windows or doors.

(2) The airplane must be in a normal ground attitude with landing gear extended.

(3) Stands or ramps may be used for descent from the wing to the ground. Safety equipment such as mats or inverted life rafts may be placed on the ground to protect participants. No other equipment that is not part of the airplane's emergency evacuation may be used to aid the participants in reaching the ground.

(4) The airplane's normal electrical power sources must be deenergized.

(5) All emergency equipment for the type of passenger-carrying operation involved must be installed in accordance with the certificate holder's manual.

(6) Each external door and exit, and each internal door or curtain must be in position to simulate a normal takeoff.

(7) A representative passenger load of persons in normal health must be used. At least 30 percent must be females. At least 5 percent must be over 60 years of age with a proportionate number of females. At least 5 percent but not more than 10 percent must be children under 12 years of age, prorated through that age group. Three life-size dolls, not included as part of the total passenger load, must be carried by passengers to simulate live infants 2 years old or younger. Crewmembers, mechanics, and training personnel, who maintain or operate the airplane in the normal course of their duties, may not be used as passengers.

(8) No passenger may be assigned a specific seat except as the Administrator may require. Except as required by item (12) of this paragraph, no employee of the certificate holder may be seated next to an emergency exit.

(9) Seat belts and shoulder harnesses (as required) must be fastened.

(10) Before the start of the demonstration, approximately one-half of the total average amount of carry-on baggage, blankets, pillows, and other similar articles must be distributed at several locations in the aisles and emergency exit access ways to create minor obstructions.

(11) The seating density and arrangement of the airplane must be representative of the highest capacity passenger version of that airplane the certificate holder operates or proposes to operate.

(12) Each crewmember must be a member of a regularly scheduled line crew, must be seated in his normally assigned seat for takeoff, and must remain in that seat until he receives the signal for commencement of the demonstration.

(13) No crewmember or passenger may be given prior knowledge of the emergency exits available for the demonstration.

(14) The certificate holder may not practice, rehearse, or describe the demonstration

for the participants nor may any participant have taken part in this type of demonstration within the preceding 6 months.

(15) The pretakeoff passenger briefing required by § 121.571 may be given in accordance with the certificate holder's manual. The passengers may also be warned to follow directions of crewmembers, but may not be instructed on the procedures to be followed in the demonstration.

(16) If safety equipment as allowed by item (3) of this section is provided, either all passenger and cockpit windows must be blacked out or all of the emergency exits must have safety equipment in order to prevent disclosure of the available emergency exits.

(17) Not more than 50 percent of the emergency exits in the sides of the fuselage of an airplane that meet all of the requirements applicable to the required emergency exits for that airplane may be used for the demonstration. Exits that are not to be used in the demonstration must have the exit handle deactivated or must be indicated by red lights, red tape or other acceptable means, placed outside the exits to indicate fire or other reason that they are unusable. The exits to be used must be representative of all of the emergency exits on the airplane and must be designated by the certificate holder, subject to approval by the Administrator. At least one floor level exit must be used.

(18) All evacuees, except those using an over-the-wing exit, must leave the airplane the by a means provided as part of the airplane's (6) equipment. ... exit, and each in(19) The certificate holders approved tion procedures and all of the emergency equipment that is normally available, including slides, ropes, lights, and megaphones, must be fully utilized during the demonstration.

(20) The evacuation time period is completed when the last occupant has evacuated the airplane and is on the ground. Evacuees using stands or ramps allowed by item (3) above are considered to be on the ground when they are on the stand or ramp: *Provided*, That the acceptance rate of the stand or ramp is no greater than the acceptance rate of the means available on the airplane for descent from the wing during an actual crash situation.

(b) *Ditching demonstration.*

The demonstration must assume that daylight hours exist outside the airplane, and that all required crewmembers are available for the demonstration.

(1) If the certificate holder's manual requires the use of passengers to assist in the launching of liferafts, the needed passengers must be aboard the airplane and participate in the demonstration according to the manual.

(2) A stand must be placed at each emergency exit and wing, with the top of the platform at a height simulating the water level of the airplane following a ditching.

(3) After the ditching signal has been received, each evacuee must don a life vest according to the certificate holder's manual.

(4) Each liferaft must be launched and inflated, according to the certificate holder's manual, and all other required emergency equipment must be placed in rafts.

(5) Each evacuee must enter a liferaft, and the crewmembers assigned to each liferaft must indicate the location of emergency equipment aboard the raft and describe its use.

(6) Either the airplane, a mockup of the airplane or a floating device simulating a passenger compartment must be used.

(i) If a mockup of the airplane is used, it must be a life-size mockup of the interior and representative of the airplane currently used by or proposed to be used by the certificate holder, and must contain adequate seats for use of the evacuees. Operation of the emergency exits and the doors must closely simulate those on the airplane. Sufficient wing area must be installed outside the over-the-wing exits to demonstrate the evacuation.

(ii) If a floating device simulating a passenger compartment is used, it must be

fabric shipped or delivered for shipment into commerce in the ordinary course of its business, or (b) to any converter, processor or finisher in performing a contract or commission service for the account of a person subject to the provisions of this Act. Provided, That said converter, processor, or finisher does not manufacture such article of wearing apparel or fabric for sale subject to this Act contrary to the terms of the contract or commission under which it acts. If any article of wearing apparel or fabric shipped or delivered for shipment into commerce for the purpose of fabricating or processing to render such article or fabric not so highly flammable, under the provisions of section 4 of this Act, as to be dangerous when worn by individuals

EFFECTIVE DATE

SEC. 12. This Act shall take effect one year after the date of its passage.

AUTHORIZATION OF NECESSARY APPROPRIATIONS

SEC. 13. There is hereby authorized to be appropriated such sums as may be necessary to carry out the provisions of this Act.

[40 FR 59889, Dec. 30, 1975]

PART 1610—STANDARD FOR THE FLAMMABILITY OF CLOTHING TEXTILES[1]

Subpart A—The Standard

Sec.
1610.1 Purpose.
1610.2 Scope.
1610.3 Requirements.
1610.4 Methods of test.
1610.5 Notes.

Subpart B—Rules and Regulations

1610.31 Terms defined.
1610.32 General requirements.
1610.33 Test procedures for textile fabrics and films.
1610.34 Only uncovered or exposed parts of wearing apparel to be tested.
1610.35 Testing certain classes of fabrics.
1610.36 Application of act to particular types of products.
1610.37 Reasonable and representative test under section 8 of the act.
1610.38 Maintenance of records by those furnishing guaranties.
1610.39 Shipments under Title I of the act.

Subpart C—Interpretations and Policies

1610.61 General discussion of flammability standard for clothing textiles (CS 191-53).

SOURCE: 40 FR 59891, Dec. 30, 1975, unless otherwise noted.

CODIFICATION NOTE: Part 1610 is a codification of the previously unpublished standard for flammability of clothing textiles, Commercial Standard 191-53, issued by the Department of Commerce, effective on January 30, 1953. This flammability standard became mandatory through section 4(a) of the Flammable Fabrics Act, as amended in 1954, and remains in effect due to the savings clause (section 11) of Pub. L. 90-189. 16 CFR Part 1609 contains the text of the Flammable Fabrics Act of 1953, as amended in 1954.

Subpart A—The Standard

AUTHORITY: Sec. 5, Pub. L. 83-88, 67 Stat. 112, as amended, 68 Stat. 770 (15 U.S.C. 1193); sec. 11, Pub. L. 90-189, 81 Stat. 568.

NOTE: All fabrics of natural or regenerated cellulose, as well as certain types of finished and unfinished fabrics made from other natural or synthetic fibers, are combustible. Such fabrics are potentially dangerous when used for clothing purposes. The relative flammability of many such materials cannot be told by observation because of the [illegible] of these factors. The [illegible] and the speed of flame spread associated with the instrument described herein. [illegible] measurement of these two factors, together with visual observation of flame intensity, will permit the separation of fabrics into three classes of flammability, thus assisting in a judgment of fabric suitability for clothing.

§ 1610.1 Purpose.

The purpose of this standard is to reduce danger of injury and loss of life by providing, on a national basis, standard methods of testing and rating the flammability of textiles and textile products for clothing use, thereby discouraging the use of any dangerously flammable clothing textiles.

§ 1610.2 Scope.

(a) The standard provides methods of testing the flammability of clothing and textiles intended to be used for clothing,[1] establishes three classes

[1] Hereinafter, "clothing and textiles intended to be used for clothing" shall be referred to as "textiles".

Footnotes continued on next page

of flammability, sets forth the requirements which textiles shall meet to be so classified, and warns against the use of those textiles which have burning characteristics unsuitable for clothing.

(b) *Specific exceptions.*—This standard shall not apply to—

(1) Hats, gloves, and footwear[4]

(2) Interlining fabrics[5]

§ 1610.3 Requirements.

(a)(1) *Normal flammability, Class 1.* This class shall include textiles which meet the minimum requirements set forth in paragraph (a)(1)(i) or paragraph (a)(1)(ii) of this section. Textiles meeting these requirements are generally accepted by the trade as having no unusual burning characteristics.

(i) *Textile without nap, pile, tufting, flock, or other type of raised-fiber surface.* Such textiles in their original state and/or after being dry-cleaned and washed as described in § 1610.4(d) and § 1610.4(e), when tested as described in § 1610.4 shall be classified as Class 1, normal flammability, when the time of flame spread is 4 seconds[6] or more.

(ii) *Napped, pile, tufted, flocked, or other textiles having a raised-fiber surface.* Such textiles in their original state and/or after being dry-cleaned and washed as described in § 1610.4(d) and § 1610.4(e), when tested as described in § 1610.4, shall be classified as Class 1, normal flammability, when the time of flame spread is more than 7 seconds, or when they burn with a rapid surface flash (from 0 to 7 seconds), provided the intensity of the flame is so low as not to ignite or fuse the base fabric.

(2) *Intermediate flammability, Class 2.* This class shall include textiles which meet the minimum requirements set forth in paragraph (a)(2)(i) of this section. Textiles meeting these requirements are recognized by the trade as having flammability characteristics between normal and rapid and intense burning.

(i) *Napped, pile, tufted, flocked, or other textiles having a raised-fiber surface.* Such textiles in their original state and/or after being dry-cleaned and washed as described in § 1610.4(d) and § 1610.4(e), when tested as described in § 1610.4, shall be classified as Class 2, intermediate flammability, when the time of flame spread is from 4 to 7 seconds, both inclusive, and the base fabric ignites or fuses.

(3) *Rapid and intense burning, Class 3.* This class shall include textiles which have burning characteristics as described in paragraphs (a)(3)(i) and (a)(3)(ii) of this section. Such textiles are considered dangerously flammable and recognized by the trade as being unsuitable for clothing because of their rapid and intense burning.

(i) *Textiles free from nap, pile, tufting, flock, or other type of raised-fiber surface.* Such textiles in their original state and/or after being dry-cleaned and washed as described in § 1610.4(d) and § 1610.4(e), when tested as described in § 1610.4, shall be classified as Class 3, rapid and intense burning, when the time of flame spread is less than 4 seconds.[6]

(ii) *Napped, pile, tufted, flocked, or other textiles having a raised-fiber surface.* Such textiles in their original state and/or after being dry-cleaned and washed as described in § 1610.4(d) and § 1610.4(e) when tested as described in § 1610.4 shall be classified as Class 3, rapid and intense burning,

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Footnotes continued from last page

[1] All the numbered footnotes are from the original printing by the Department of Commerce. All the lettered footnotes are new.

[2] Refer to sections 2 and 4 of the Flammable Fabrics Act of 1953, as amended in 1954, set out at 16 CFR Part 1609, for the scope of the Standard.

[3] Refer to sections 2(d) and 4 of the Flammable Fabrics Act of 1953, as amended in 1954, set out at 16 CFR Part 1609 for exceptions to this exception.

[4] Interlining fabrics are not considered dangerously flammable when used as interlinings. When used for other purposes they should be tested and rated the same as any other fabrics.

[5] On August 23, 1954, the Flammable Fabrics Act was amended, changing the test for the time of flame spread for plain-surfaced fabrics, provided in paragraphs 3.1.1.1 (now § 1610.3(a)(1)(i)) and 3.1.3.1 (now § 1610.(a)(3)(i)), by reducing the burning time from 4 to 3½ seconds. For the purpose of the administration of that act, therefore, the 3½ second burning time for plain-surface fabrics is applicable.

[6] See footnote d.

when the time of flame spread is less than 4 seconds and when the intensity of flame is such as to ignite or burn the base fabric.

§ 1610.4 Methods of test.

(a)(1) *Number and size of specimens required.* Five specimens, each measuring 2 by 6 inches, are required for each test.

(2) For textiles without a raised-fiber surface the long dimension shall be that in which they burn most rapidly, and the more rapidly burning surface shall be tested. To establish the long dimension and the surface, preliminary tests are made as described in paragraph (g) of this section, with specimens cut in different directions.

(3) For textiles having a raised-fiber surface, the direction of the lay of the surface fibers shall be parallel with the long dimension of the specimens. For this type of textiles with varying depths of pile, tufting, etc., the specimens are taken from that part and tested on that surface which has the fastest rate of burning.

(4) If the specimens in the preliminary test, when tested as described in paragraph (g) of this section, do not ignite or are very slow burning, or should have a fire-retarding finish, a swatch large enough to provide the specimens required for the test, with allowance for shrinkage in dry cleaning and washing, is subjected to the dry cleaning and washing procedures described in paragraphs (d) and (e) of this section. The specimens for the flammability test are then taken from it.

(5) The specimens required for testing, each 2 by 6 inches, are marked out on the back (or under side) of each sample with the long dimension in the direction in which burning is most rapid, as established in the preliminary trials. The end of the specimen toward which and on the face of which burning is most rapid is identified by attaching a staple to it. The specimens are then cut out.

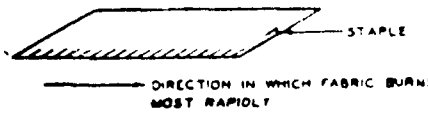


FIGURE 1.—Specimen showing staple.

(b) *Flammability tester* [1] The flammability tester consists of a draft-proof ventilated chamber enclosing a standardized ignition medium, sample rack, and automatic timing device.

(1) *Draft-proof chamber with vented top (A, fig. 2).* This metal chamber prevents air circulation around the specimen rack and flame, but permits free ventilation for rapid oxidation. The chamber is 14 ¾ inches wide, 8½ inches deep, and 14 inches high. There are 12 half-inch holes equidistant along the rear of the top closure. A ventilating strip is provided at the base of the sliding glass door in the front of the apparatus.

(2) *Specimen rack (B, fig. 2).* The specimen rack provides supports for the frames in which the specimens are mounted. The angle of inclination is 45°. Two guide pins projecting downward from the center of the base of the rack travel in slots provided in the floor of the chamber so that adjustment can be made for the thickness of the specimen in relation to the flame front. A stop is provided in the base of the chamber to assist in adjusting the position of the rack.

(3) *Specimen holder (C, fig. 2).* The specimen holder consists of two 5/16 inch matched metal plates with clamps mounted along the sides, between which the specimen is fixed. The plates are slotted and loosely pinned for alignment. The two plates of the holder cover all but 1½ inches of the width of the specimen for its full length. The specimen holder is supported in the draft proof chamber on the rack at an angle of 45°. Five specimen holders are provided.

(4) *Indicating finger (D, fig. 2).* The forepart of this finger touches the specimen when the rack is adjusted. By means of this finger the thickness

[1] This apparatus is manufactured by the United States Testing Co., 1415 Park Avenue, Hoboken, N.J. Blueprints of working plans for the manufacture of this apparatus are available, at a nominal charge, from the above-named company.

38-686 O - 79 - 23

Carry-On Baggage

1. Items which may be retained by the passenger as "carry-on baggage" include briefcases, attache' cases, typewriters, and other articles of proper dimensions to fit under the passenger seat or in the enclosed overhead storage compartments (these articles must be retained in the passenger's custody). Include the measurement of carry-on baggage, except live animals, in the passenger's free allowance and/or excess charge. Carry-on baggage must be of a size that it will fit beneath passenger seats.

2. Federal Air Regulations require carry-on baggage to be stowed during take-off and landing. Baggage stowed under a seat should not infringe upon the leg room of another passenger. This can usually be accomplished by placing the bag under the seat immediately in front of the passenger's seat. Passengers seated in the forward row of seats of a compartment (facing a bulkhead) should stow their bags under a seat in front of an empty seat or under the rear seat of a compartment. Encourage passengers with carry-on baggage to select other than bulkhead seats or seats near emergency and door exits, since there is no underseat baggage stowage available for passengers sitting in those seats.

SAFER Escape Slide Sub-Committee

Meeting September 6 and 7, 1979

I. Discussion

The Continental Airlines DC-10 accident at LAX [1] caused an escape slide/raft to collapse as a result of exposure to radiant heat from burning fuel. There are presently no requirements for slides or slide/rafts to resist heat radiation from fuel fires, nor is there an established laboratory scale test method which accurately simulates exposure to a fuel fire radiation.

Development and evaluation of overall slide, slide/raft constructions such as basic fabrics, fabric coatings, protective overcoatings, stitching methods, and seam cementing materials all require adequate heat radiation test apparatus and proceedures.

FAA, NAFEC is presently conducting a program to determine effects of heat radiation on pressurized escape slide, slide/raft materials utilizing an infra-red laboratory heat radiation source.[2] Tests will also be conducted on full size slides and slide/rafts, using a large (30' x 30') heat source of burning fuel.

FAA, NAFEC is also conducting a program to evaluate the feasibility of applying a heat reflecting coating to escape slides and slide/rafts in service.

Current materials with heat reflecting finishes, and improved fabrics and coatings for escape slides and slide/rafts are being evaluated by the industry.

1 NTSB report #NTSB AAR-79-1

2 NA-78-41-LR

II. Recommendations

a) Develop a practical laboratory test method to correlate the heat radiation effect from a fuel fire on escape slides and slide/rafts.

Test method to be developed by FAA-NAFEC with industry support through the SAFER Escape Slide Sub-Committee.

b) Conduct a test program to evaluate available slide and slide/raft materials including the construction of the unit, using test methods established in a.). This is a prerequisite for considering heat radiation requirements for slide and slide/raft materials.

The test program to be developed by FAA-NAFEC with industry support through the SAFER Escape Slide Sub-Committee.

c) Evaluate reflective coatings which are developed for slide and slide/raft retro-fit. Testing be conducted using test method a.) and full scale pool fire tests. Determine that the selected reflective coatings be compatible with all other slide and slide/raft requirements including repacking. The evaluation to be conducted by FAA-NAFEC with industry support through the SAFER Escape Slide Sub-Committee.

NOTES

1. The program outlined above will be periodically reviewed and modified, if necessary, as the tests are completed, by the SAFER Escape Slide Sub-Committee.

2. Anticipated completion of the three phases of this program are:

   Phase a.) By January 1980
   Phase b.) By May 1980
   Phase c.) By May 1980

SAFER Escape Slide Sub-Committee

Lou Brown,	FAA-NAFEC
Ian Goodyear,	McDonnell Douglas Corp.
Dick Kerr,	Reeves Bros.
Paul Langston,	E.I. Du Pont & Co.
Czeslaw Wojeik,	Boeing Co.
Jarvis Fargo, (Chairman)	Lockheed-California Co.

PASSENGER SMOKE HOODS

INTRODUCTION

- TOXICITY GROUP FINDINGS
- IMPROVEMENTS

80 GEN 21295

PASSENGER SMOKE HOODS

BACKGROUND

PRIOR INVESTIGATIONS

- FINAL PROJECT REPORT
- AIA FIRE SUPPRESSION AND SMOKE AND FUME PROTECTION
- ATA REPORT
- CAMI REPORT

BOEING 21296

SMOKE HOODS

DEVELOPMENTS

- HOOD WITH O_2 SUPPLY
- HOOD WITH AIR SUPPLY
- MANUFACTURER CONCERN

80-GEN-21297

A-78

PASSENGER SMOKE HOODS

CONCLUSIONS

NO NEW ADVANCEMENTS THAT SOLVE CONCERNS OF

- DELAY IN EVACUATION
- CONFUSION IN USE
- RISK OF SUFFOCATION

80-GEN-21298

SAFER ADVISORY COMMITTEE

TECHNICAL GROUP ON COMPARTMENT INTERIOR MATERIALS

SUB-GROUP ON R&D REVIEW

DRAFT FINAL REPORT - MAY 1980

The sub-group on R&D Review met at the Ames Research Center on August 13 and 14, 1979 and the Jet Propulsion Laboratory on March 3, 1980. Lists of attendees are enclosed (Enclosure 1 and 2). The group reviewed major segments of the current and planned R&D program and attempted to arrive at a consensus on objectives, goals and priorities.

The first day of the meeting in August 1979 was spent in reviewing current programs and plans of Boeing, Douglas, Lockheed, the FAA, and NASA. Topics covered included materials development, testing and modelling. Approximate funding is:

	1979	1980
FAA	$950K	875
NASA	1485	895
3 TRANSPORT MANUFACTURERS	2200	1900

The second day was spent discussing issues and priorities and preparing initial write-ups.

Subsequent to this meeting, it was determined that a long term plan for mathematical modelling was desired. JPL was requested to prepare this plan and iterate with industry and other agencies. It was also decided to examine toxicity within the context of

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modelling, testing, and materials development and to add that topic to this sub-group. As these activities proceeded, it became clear that a quantitative fire scenario, the need for which was identified at the August 1979 meeting, was needed as soon as possible to provide a focus for the disciplinary research. As a result, the group met again in March 1980 to review a straw-man scenario, the proposed modelling plan, and the issue of toxicity.

This report includes a summary and perspective, followed by detailed discussions of: Materials Development, Criteria for design, Modelling, Testing, Toxicity, and a follow-up organization. Each section includes a discussion of proposed research objectives; however, because of the variation among the status and understanding of the several disciplines, there is considerable variability in the description of the needed effort. Where possible, schedule objective and required funding are described, but in some cases this could not be accurately forecast.

1. Summary and Perspective

Aircraft cabin fire safety technology has historically been focussed on polymeric material development. Most of these materials, which are functional, comfortable, decorative, and economical, will burn under certain conditions. Past research has emphasized modifying these materials or developing alternative materials to reduce (but not necessarily eliminate) burning and

the evolution of smoke and toxic gases. We are able to test these materials in the laboratory and provide relative data on burning (e.g., flame spread, heat release rate), smoke evolution, and toxic effluent. The problem; however, is to relate such data to behavior in an aircraft fire and to ~~provide adequate safety~~ assess its relationship to survivability in a post crash fuel fire in the design of the aircraft.

It is simplistic to demand that we continually change to materials that burn less readily or give off less smoke or toxic gas. Before we require the investment for such changes, we should be able to define, even approximately, the increase in ~~safety~~ survivability that would accrue. To do so we should be able to predict (analytically or empirically) the course of a fire in a real aircraft containing a mix of materials. We want to be able to predict how much additional escape time would be provided by a change in seat material from, e.g., one with a 1.0 inch burn length in the bunsen burner test to material with 0.5 in burn length. And we would need to predict ~~(approximately)~~ the ~~absolute~~ escape time. For example, in a post-crash fire in which all of the people evacuate within 1-3 minutes, no real increase in ~~safety~~ survivability would be provided by changing from a material that allowed 10 minutes escape time to one providing 20 minutes escape time.

1.1 Materials

There is a perception that the flammability of aircraft interior materials constitutes a major threat to passenger safety in the

case of post-crash fires. Accident statistics do not support this perception. ~~Only a small fraction of accident victims die from~~ are not the major causes of death. Burning or suffocation. Many of the current (wide body) interior materials perform quite well as indicated by observations of recent accidents. The ability to improve upon the fire resistant design ~~these materials~~ depends on developing improved realistic criteria based upon ~~realistic~~ well defined fire scenarios, and ~~validated~~ test methods. Materials efforts in the near term should concentrate on ~~decorative inks and films, seat cushions and arm rests, floor coverings, upholstery, and drapes to improve fire resistance without sacrificing life.~~ thermoplastics, foams, films, and adhesives. In addition, efforts are also needed on window materials which can resist fire penetration ~~to the same degree as current sidewall material~~, and ~~more heat resistant (when deployed) evacuation slides~~ evacuation slides with more heat resistance.

1.2 Criteria for Design

One of the limiting factors in defining requirements for interior materials is the lack of realistic criteria based on well defined fire scenarios. The most important threat appears to be an otherwise survivable take-off or landing crash followed by an external pool fire with the fuselage intact and only door size openings. A reasonable quantitative definition of such a fire is incorporated in the body of this report. In-flight internal fires are readily detectable and extinguishable and, although part of the design requirement, do not appear to be the pacing requirement. Current

wide body interior materials appear to function adequately as fire barriers to external fires and it is not obvious at this time that significant additional effort is needed in the area of barrier material technology.

One of the major issues which surfaced during the discussion was to consider the improvement of cabin fire safety using an overall systems approach. The understanding of the total threat to the occupants of heat, smoke, and toxic and irritant gases and their interaction must be combined with detection, extinguishment, and evacuation considerations in order to provide realistic design requirements. The old approach of trying to improve each aspect separately does not necessarily provide the most significant or expeditious improvement in safety. For example, there was a strong feeling that substantial further efforts in reducing interior material flammability were predicated on acceptance of the inevitability of a substantial pool fire; whereas fuel modification or fire suppression research might have more potential in terms of more substantial improvements in safety.

1.3 Modelling

The ability to analytically or empirically describe a fire and its progress is ~~necessary~~ desirable for designing interior systems and selecting materials, and ~~also to~~ relate small and full scale test data to ~~performance in an~~ accident. Fire modelling

is currently in the early stages of development. It was felt that a concerted effort should be made to accelerate the empirical correlation of lab and full scale tests ~~as well as a long term investment in~~ and to advance analytical modelling development.

1.4 Testing

Testing methodology was singled out as a technology requirement because of the lack of reliable predictive methods which are demonstrated to be correlated with performance in an accident. Near term focus should be on well instrumented full scale tests (e.g., FAA's C-133 tests and NASA's B-737 tests) to provide quantitative design requirements and to realistically evaluate current and new materials systems and configurations. A mock-up test should be developed to provide similar evaluations in the future at lower cost. Also, further development is needed to develop correlation between lab tests and full scale/accident performance.

1.5 Toxicity

It is not clear based upon available evidence whether or not the potential evolution of toxic gases presents a critical threat ~~(relative to the other threats such as heat and flame)~~ to aircraft cabin fire survivability safety. We recommend that research be conducted to clarify this issue. ~~Simultaneously we recommend proceeding with a research program which assumes that there is such a critical threat in order to allow a valid design base.~~

1.6 Follow-Up Organization

The group felt the need for an on-going forum for exchange of information, co-ordination of research and technology planning, and development of standards. After exploring several alternatives, it was decided to establish such an activity within the existing ASTM Committee F-7.

2. Materials Development

Recent FAA test results ~~clearly~~ indicate that a continued effort is required to improve provide ~~fire-resistant~~ seating materials, decorative and structural panels, ~~floor-coverings~~, windows and ~~drapes~~ slides. It appears at present that the major threat to human survivability in a crash-survivable post-crash fire accident from a materials point of view, are the seats, and the windows, and ~~the decorative panels.~~

Considerable progress has been made in fire hardening the basic undecorated panel from the point of view of fire involvement and fire containment, however, improvements can be made. ~~Unfortunately because of existing processing limitations, decor and costs, little progress has been made in the development of what should be called~~ decorative surface ~~systems. The major activity in the near term that should have the maximum payoff with respect to fire survivability and the post-crash-fire situation must take into account the component and the performance of the combined component in the decorative panel.~~ Activities should be directed in development

of films, inks, pigments and adhesives which lend themselves to current production methods at reasonable cost and with comparable decor that can resist the tendency to flashover and toxic gas emission under heating rates in excess of 5 watts/cm^2. ~~No current materials systems do this.~~ Although not tested in full scale, data from both aircraft accidents and laboratory tests, suggest that some highly flammable thermoplastics which drip and form showers of burning droplets, ~~should be eliminated from aircraft interior systems. Limited progress has been made to date to find new candidates for these applications~~. Recent advances with new thermoplastics make a re-examination of these thermoplastics worthwhile.

It is clear from both laboratory and full-scale tests that considerable fire containment benefits can be derived from improvements in the fire hardness of transparent window materials. These windows have a promise for a quick and cost effective solution to the hazard of fire penetration through window openings which occurs from the failure of conventional materials. It has been already demonstrated that the new fire-resistant NASA developed transparent materials reduce this hazard. A considerable developmental effort will be necessary, but rather short term, to get these new windows into production. This development calls for the preparation and study of composite transparent laminates and significant improvement in the edge attachment technology.

As far as cushioning and upholstery materials are concerned for the short term, it has been recently demonstrated it may be possible to reduce the threat of fire spread throughout the aircraft by the use of a fire blocking layer comprising a high char yield elastic foam to modify current conventional seats or the use of polyimide foam.

~~Little progress has been made recently in developing safer fabrics for upholstery, rugs, drapes, etc.~~ Recent advances with PBI fibers and new fire-resistant fiber coatings may offer some long term ~~help.~~ improvement for interior fabrics However, ~~within the state of the art, improvements are possible in the short term with windows, seats and decorative panels.~~

~~Significant~~ Improvements in fire containment capability of aircraft insulation, ~~and resistance to fire spread of the coverings which support them~~ may also contribute to the long term ~~survivabrility in the post-crash fire. This is illustrated by the recent application of~~ polyimide foam insulation, support films by ~~Lockheed for the L-1011.~~

Current techniques for improving the fire resistance of inflated elastomeric slides through the use of reflective coatings, may as well be adequate for the short term egress (90 seconds) but certainly ~~requires much more significant improvement for longer egress times which are substantially the real goal of our current and projected materials development program.~~

With regard to the R&D funds anticipated to be useful and necessary to achieve the improvements discussed above, it would seem that near term improvement (through 1983) ~~in seating materials~~ should be ~~accomplished by 1983 with an investment of about $300,000 for both materials and qualifying full-scale tests.~~ funded at about $[illegible] per year divided approximately equally among seats, windows and decorative films. Long term seat development improvements could, from a research point of view, effectively utilize something like $150,000 a year for the next three to five years and is modestly high risk research involving the exploitation of recently discovered polymers useful for foams and fabrics.

The window requirements are also similar requiring immediately the production of prototype windows and edge attachment devices for conducting environmental, operational and fire tests. The resources requirement for this combined effort could amount to as much as $300,000 over a two year period to bring these windows to a set of production and performance specifications. Research on new interior decorative systems along conventional lines such as films, adhesives and inks, etc., will proceed very slowly and no short term answer is expected. This continuing R&D could effectively utilize approximately $200,00 per year for a period of three to four years. There are research opportunities to look at new transparent, unsupported films, such as, polyetheretherketone, and fire-heat resistant adhesives currently being studied such as phosphorylated epoxies.

3. Criteria for Design

As described above, a major need is to be able to quantitatively describe ~~the characteristics of a post-crash fire, establish~~ and establish fire design criteria, human tolerance limits, ~~then design aircraft material to allow~~ and subsequently improve the design process to provide ~~to ensure~~ a safe escape in sufficient time. The current FAA C-133 tests will provide much information on the design fire. Until such data are available, the straw-man scenario described below is proposed as a focus for technology activities.

3.1 Aircraft Cabin Fire Scenario

3.1.1 General

A wide body jet transport with a passenger load factor of 57 percent crashed on the runway of a major airport following an abnormally ~~steep landing~~ High descent rate. The accident occurred on a sunny afternoon.

3.1.2 Postcrash Fuselage Description

Except for ~~a rupture~~ an opening in the fuselage ~~skin above the cabin floor level~~ on the right side, the fuselage was otherwise intact. The size of the ~~rupture was~~ opening is approximated by a rectangle 76 inches high and 42 inches wide. ~~Although~~ The two forward doors on each side of the fuselage were jammed, and passengers and crew members - none of whom were immobolized or traumatized -- utilized the remaining six doors to evacuate the airplane. During the crash deceleration the landing gears were sheared off and the airplane eventually came to rest on its belly in a level orientation. All emergency lighting systems operated properly.

3.1.3 Fire Description

~~During the crash deceleration~~, an integral tank in the right wing was penetrated by debris, ~~causing the~~ spillage ~~of~~ fuel which was immediately ignited by frictional sparking. A trail of burning fuel was observed behind the decelerating airplane. ~~When~~ the airplane came to rest a large external fuel fire erupted immediately in the vicinity of the fuselage rupture. (~~Note:~~ Based on past accident analyses, ~~other plausible~~ openings for the entry of fire are inadvertently opened doors ~~or~~ small ruptures beneath the cabin floor line.) Other door openings were not subjected to the pool fire, which involved several thousand gallons of fuel. The pool fire reached heights of approximately 75 feet, extended beneath the belly of the fuselage and completely covered the rupture. The pool fire flames were attached to the fuselage. Only those cabin materials very close to the ruputure opening were subjected to the intense heat and flames ~~generated by the fuel fire~~. A relatively steady 3 mph wind was blowing in a direction perpendicular to the fuselage. The pool fire was upwind of the fuselage. The radiative heat flux in the fire may have reached 14 Btu/ft^2-sec and at the center of the cabin at the rupture would have been at least 1.8 Btu/ft^2-sec. There was moderate penetration of flames from the fuel fire primarily ~~onto the~~ in the vicinity of the ~~ceiling~~ next to the ~~rupture~~ opening. (~~Note: Whether the fuselage is a wide~~

body type* or a standard body* type will have a crucial bearing on the development of the fire and its hazards. For example, compared to a standard body jet, a wide body jet is significantly more resistant to burn through by an external fuel fire, furnished with more flame retardant cabin materials, and encompasses a larger cabin volume with possibly greater dilution of combustion products.)

*this terminology refers to the era in which the aircraft were developed rather than the size. Wide body aircraft of the 1970's have more burn-through resistant sidewall panels than older narrow bodies of the 1960's.

3.1.4 Evacuation Description

At the first indication of fire at the ruptured fuselage location, those passengers nearby immediately began moving away from the ~~fire~~ heat.

Surviving passengers and crew utilized all six operational doors to evacuate the airplane. Estimates for the evacuation time ranged from 90 seconds to 3 minutes. (Note: It is recommended that full-scale fire tests be conducted for a period of 5 ~~minutes in order to completely cover the time scale of potential interest.~~ for technology development, a 5 minute exposure time be considered to cover most evacuations.) The shell of the fuselage remained primarily intact during the evacuation, ~~although the cabin was eventually gutted.~~

3.1.5 Design Fire Considerations

-An important feature of an aircraft postcrash cabin fire is the possibility of intense thermal radiation through a fuselage opening caused by a large external fuel fire.

-In order to be representative of the large fuel fires characteristic of many aircraft accidents, a design fire should be "optically thick" to produce this intense radiation.

-The severity of the fire exposure to interior materials increases with the degree of flame penetration.

-Cabin hazards arising from the fuel fire are dependent on the amount of flame penetration into the cabin. The degree of flame penetration for the design fire must be selected to provide cabin hazard levels well within human survival limits over a prescribed time interval.

3.2 Human Tolerance Limits

Some information is now available on the limits of human tolerance to heat, smoke, and some toxic gases; however, more work is needed in defining the effects of irritant gases and a definition of human tolerance from a system point of view. The combined effects of heat, visual disorientation, and the presence of irritating or toxic gases on the behavior of passengers needs to be evaluated relative to cabin egress design. Efforts along the line of the FAA Combined Hazard Index (CHI) program are needed. It is estimated that a major effort is needed for 3

years to develop a preliminary useful design criteria.

3.3 Egress, Lighting, and Evacuation

These activities do not fall under the category of cabin interior materials; however, the design and development of technology must be done in conjunction with establishing a ~~combined hazard index~~ system approach for evaluating safety.

3.4 Barrier Considerations

In the case of a post-crash fire in which the fuselage is not significantly ruptured, current sidewall materials appear to provide adequate protection from burn-through for reasonable evacuation times. Efforts should be made to upgrade transparencies as described in section 2.0 on Materials Development. Technology appears to be nearly in hand to provide reasonable fire barrier protection for unattended lavatories, carry-on storage compartments, and cargo compartments.

4.0 Modelling

This activity is seen as the centerpiece of cabin fire safety technology. In order to intelligently relate material laboratory test results with aircraft cabin geometry, the fire scenario, and human tolerance limits, it is necessary to have analytical and/or empirical tools to model the fire. There are two aspects to this issue which are complementary and integrated activities. They are:

1. Near term development of mathematical tools to predict the progress of burning, thermal (temperature distribution) and gas

species distributions in a defined geometry.

2. Short term analytical and empirical methods ~~based on~~ to correlate full scale and model testing and correlation with laboratory testing.

~~These two aspects should not be considered as competitive activities, but rather both part of a continuum of activities from which increasingly valuable modelling tools emerge.~~

4.1 Short-Term Modelling Plan

The base for the development of such a methodology has been laid down with several programs including the FAA contract with McDonnell-Douglas for the "Combined Hazard Index" (CHI), Boeing fire test methodology program started in 1974 and the NASA-JSC contract on fire test methods which Boeing completed in October 1978. There are probably others, but these are notable because they developed within two of the three major airframe companies exceptional knowledge pertaining to the problems of material evaluation and fire threat definition. This background combined with the knowledge of airplane construction and parts fabrication provides a currently unique capability to develop a methodology to evaluate the fire performance of materials in a fashion both effective in materials control and practical in application.

The program on the attached chart is proposed to develop this capability in the shortest time possible. It is recommended that a transport manufacturers industry association (e.g. AIA) ~~the AIA~~ be recognized as representing a major portion of that knowledge necessary for the short term solution and that the FAA

the major transport manufacturers
allocate funds to ~~Lockheed, Douglas, and Boeing~~, to operate jointly in Phase I. The FAA, through FAA TC NAFEC, would provide a focal point and monitoring function. Expert opinion for state-of-art solution would be solicited and documented where needed.

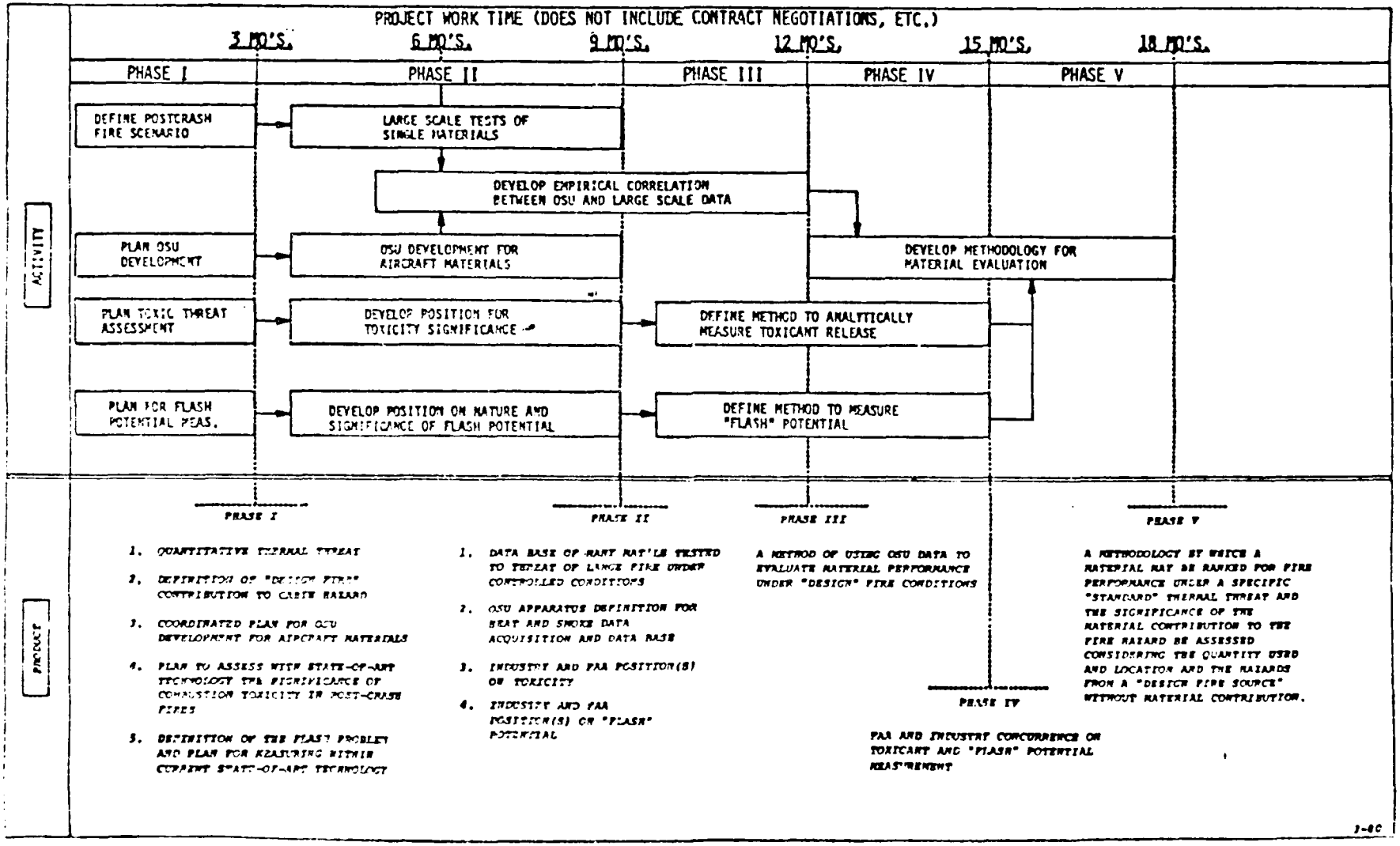
During Phase I the following phases would be more completely defined, including participation by FAA-TC ~~NAFEC~~, FAA-CAMI, NASA, etc. as would the level of funding required by the industry ~~AIA companies~~. Much of the work required in Phases II-V has already been started during the previously noted programs. The main ingredients for the success of such a program are: (1) a sense of urgency to resolve the material evaluation problem within the state-of-the-art, (2) recognition that in this case only the airframe companies have the test correlation, airplane design, material selection and laboratory test application background to develop ~~the~~ practical solutions in a timely fashion, (3) a means of formally requesting and obtaining the participation of the industry ~~AIA~~ members in the effort, and (4) timely testing and analysis support by the NASA and FAA-CAMI and effective testing and program administration support by the FAA-NAFEC.

It would be expected that at the end of each phase the FAA would be given a formal report and could review it with other experts as desired, before embarking on the next phase of the program. The cost of the program would probably by $1-1.5 million for the AIA companies (depending on how much new data was needed and the time-

liness to take advantage of current IRAD programs) not including support by the FAA-~~NAFEC~~ Tc. On six month intervals, progress could be compared to the long term model development and the need for continuation or change in direction of either or both determined.

BOEING

NUMBER
REV LTR



SHEET

AIRCRAFT FIRE MODELING TECHNOLOGY PLAN

PREPARED BY

JET PROPULSION LABORATORY

C. P. BANKSTON

L. H. BACK

APRIL 11, 1980

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I. INTRODUCTION

This document describes a broad, long-range Fire Modeling Technology Plan which has been developed in response to recognized fire safety needs in commercial aviation and for the Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee. It is designed to provide analytical models which possess well defined predictive capabilities with particular emphasis on user needs. Furthermore, since analytical methods should be developed in conjunction with related experiments, this plan also includes test programs which are necessary to establish effective and valid predictive techniques.

The planning process was initiated on October 1, 1979, and includes input from the major airframe manufacturers, Federal Aviation Administration, National Bureau of Standards and NASA. In addition, as part of the planning process the Definition of Requirements, Phase 1, was substantially completed by JPL and the findings are presented herein.

Finally, note that this long-range plan would be complementary to the short-range plan for the development of empirical correlation methods (for materials evaluation) which has been proposed by Boeing. Also, detailed plans for the development of hazard evaluation methodologies are left to other specialists.

II. BACKGROUND

1. Implications for Fire Modeling Technologies

A. Aircraft Design and Materials Development

The ability to accurately predict fire characteristics will allow "a priori" determination of the effects of different interior configurations, fire detection and suppression systems, ventilation geometries, etc., on fire behavior. In addition, modeling of the burning response of materials will allow evaluation of the effects of different material parameters on fire characteristics, and thus provide insight for materials development. Also, it should be emphasized that while an effective modeling technology cannot eliminate laboratory and full scale tests, it will allow for the planning of fewer, more meaningful tests.

B. Hazard Evaluation

The ability to predict such quantities as gas temperature, toxic specie concentrations, smoke density and heat fluxes is necessary in order to evaluate life hazards in the fire environment. For example, a wide variety of design options and material characteristics can be studied to determine their relative effects on hazardous fire phenomena. Also, these analyses might influence evacuation plans or other operational procedures.

C. Regulatory Standards

Fire modeling can assist in the development of regulatory standards by providing information on the impact on aircraft fire safety of material standards, design guidelines and operational constraints. In addition, combined laboratory and full-scale model analyses will aid in the establishment of meaningful testing and acceptance criteria.

2. Modeling Methodologies

Fire modeling as discussed in this Plan is defined as the mathematical description of physical and chemical fire phenomena; and the description of the (local) environment affected by those phenomena. These processes are usually described by conservation equations governing the transport of mass, momentum, energy, individual gas species and smoke. Models may then predict (but are not necessarily limited to) the following quantities: gas temperature, surface temperatures, fuel burning rate, radiation, gas velocity, gas specie production and concentrations, and smoke production. Current fire modeling methodologies can be divided into four categories:

A. Overall Modeling Methodologies

These methodologies are usually applied to the total fire scenario and are intended to predict the overall progress of the fire and its interactions with the environment. There are three overall methodologies:

(i) Global Models. These predict the overall bounds of fire development by application of global gas specie, momentum and energy balances; but they cannot, in general, predict the detailed progress and characteristics of the fire. JPL's Limiting Energy Release Criteria and the analysis utilized in Boeing's interior materials fire test methodology are examples of global models.

(ii) Zone Models. Zone models predict the progress of a fire, but usually require considerable empirical information (burning rates, specie evolution, entrainment rates, flame heights, etc.) for application. The zone modeling methodology has undergone considerable development in recent years and experimental evaluation is presently underway.

In general, however, the applicability of this approach has not yet been adequately analyzed. It should also be noted that the success of the zone modeling approach is dependent upon the ability to define meaningful zones in a given fire enviornment. Zone models have been developed at McDonnell-Douglas (CHI), Dayton Research Institute (DACFIR), National Bureau of Standards, Harvard (Computer Fire Code) and Illinois Institute of Technology (RFIRES).

(iii) Detailed Field Models. These are intended to describe in detail the flow field, temperature and specie distributions, energy transport and burning rates in the fire environment. Physical and chemical fire phenomena and the description of the local environment affected by those pheneomena are mathematically described by appropriate conservation equations. However, limited work has been carried out in this area due to the lack of fundamental information on turbulent combustion, radiation, thermochemical and thermophysical data, and inherent computational complexities. Detailed field models have been or are presently being developed at the University of Notre Dame (UNDSAFE) and at JPL (EFDM).

B. Detailed Laboratory Scale Modeling

This modeling methodology is associated with small-scale experiments or test methods and is utilized to describe and interpret observed materials responses to a specified fire loading. Such modeling is necessary in order to provide basic information on material properties for design and as an input to full-scale models. In addition, laboratory-scale modeling can assist in the interpretation of small-scale test results in terms of the full-scale fire environment.

C. Physical Scale-Modeling

Physical fire modeling comprises the geometric scaling of a particular fire scenario such that appropriate dimensionless parameters remain constant. In this manner, reduced-scale experiments may be conducted and measured phenomena related to the full-scale situation through derived scaling relationships. Pressure modeling and Froude modeling are examples of this methodology.

D. Empirical Correlation

This methodology utilizes small-scale test data to predict the relative performance of materials in a given full-scale fire situation. The technique involves determination of the appropriate mathematical treatment or weighting for small-scale data which will then correctly correlate materials performance with measured full-scale results. To date, empirical correlation methodologies have not yet been successful in characterizing the burning characteristics of aircraft interior materials.

3. Justification

Consideration of the above-described state of fire modeling technology has led to several important conclusions:

A. The applicability of existing zone models in terms of user needs has not yet been adequately established although this methodology has undergone the most development.

B. Detailed field and laboratory-scale models are still in the early stages of development. Thus, further development is necessary in order to obtain a practical, working methodology. Also, a successful detailed modeling methodology presumably would then provide more detailed information and could also be applied to a wider variety of scenarios.

C. Fire modeling efforts to date have emphasized enclosure fires. However, the primary aviation fire hazard is the post-crash fuel fire which enters the fuselage via an opening and then spreads through the interior. Thus, there is a need for new models which describe the external fuel-pool fire adjacent to the fuselage.

D. Successful extrapolation of small-scale test data to predict full-scale fire performance has not yet been achieved. Thus, development of methodologies which will aid in the appropriate interpretation of small-scale test methods is needed.

III. OBJECTIVES

The overall objective of this Fire Modeling Technology Plan is to develop analytical and experimental methods for use in aircraft design and testing to reduce the post-crash fire hazard. Specific objectives developed in response to previously discussed needs are:

1. Determine the capabilities of existing modeling methodologies relative to user needs; and accelerate activities to improve these methodologies with regard to the stated needs.
2. Develop a detailed, analytical fire dynamics model that will describe the post-crash fire scenario; and develop other new modeling methodologies as required.
3. Determine the capabilities of existing small- and large-scale test methods for model application.
4. Develop and refine appropriate test methodologies which can be used with models to give well defined predictive capabilities.
5. Develop hazard evaluation modeling methodologies.

IV. APPROACH AND IMPLEMENTATION

This section details the approach to be followed in implementing and carrying out the Fire Modeling Technology Plan. The Plan is divided into six phases as described below and in the attached Milestone Chart and Flow Diagram. Phase 1 has been substantially completed by JPL during the planning process and the resulting Fire Modeling Technology Requirements are presented here in detail. In the presentation of Phases 2 through 5, the approach and recommendations for implementation of the plan are presented.

PHASE 1: Fire Modeling Technology Requirements

This phase presents fire modeling technology needs in terms of model predictive capabilities and scenarios, and corresponding small- and large-scale test capabilities. These findings have been based upon consideration of pertinent fire phenomena and the burning response of materials to those phenomena and identification of appropriate fire scenarios. A summary of inputs from industry and government which formed the basis for these requirements is given in the Appendix.

A. Models

(i) Overall Modeling Methodologies. A broad overall modeling methodology is needed to:

a. Evaluate Design - The designer needs to run sensitivity or parametric analyses for end design confirmation. The model must be capable of evaluating:

(1) material types/combinations;

(2) material location/orientation;

(3) interior geometries; and

(4) ventiliation characteristics;

for the post-crash external fuel fire scenario.

b. Assist large-scale test programs - Modeling will aid in planning test protocol and instrumentation.

c. Predict Localized Phenomena - The overall modeling methodology should predict the following quantities:

(1) temperatures;

(2) heat flux;

(3) toxic gas concentrations;

(4) smoke concentration;

(5) flame propagation; and

(6) flashover potential

Finally, specific recommendations for the development of an overall modeling methodology are:

a. Improvement of existing methodologies.

b. Development of a detailed post-crash fire modeling methodology.

c. Development of other "new" models as identified in Phase 3.

Note also that the development of an overall modeling methodology will require inputs from small-scale testing and modeling as indicated below. Inputs which may be required include initial conditions, flame spread characteristics, specie generation and heat release.

(ii) Small-Scale Test Modeling. This methodology is needed to interpret small-scale test results in terms of actual fire conditions and to provide input components for overall modeling methodologies. To achieve these objectives, specific needs for small-scale modeling are:

a. A model for the OSU chamber test environment is needed, as this apparatus has been identified by SAFER as the most promising test method for development into a regulatory tool.

b. A modeling methodology to predict flame spread is needed in connection with the development of a new flame spread test method (see Experimental/Testing Requirements).

c. Valid scaling relationships are needed for reduced-scale physical modeling experiments.

d. Empirical correlation of small-scale test data with full-scale results is needed so that appropriate materials screening and certification methods can be developed. Such an effort could be conducted in response to short-term needs for appropriate material test methods; and a program to accomplish this specific task has been proposed by others.

B. Experimental/Testing

(i) Full-Scale Testing. Full-scale tests are needed to simulate the post-crash external fuel fire and the response of cabin interior materials to that fire in order to:

a. Validate model results.

b. Validate small-scale modeling and testing results.

(ii) Small-Scale Testing. Small-scale testing is needed for :

a. Small-scale modeling validation.

b. Direct input to overall modeling methodologies.

c. Formulation and validation of scaling relationships.

d. Development of empirical correlations.

Specific needs to accomplish small-scale testing objectives are:

a. Obtain OSU Chamber test data.

b. Develop flame spread test and data.

c. Determine materials' thermochemical and thermophysical properties for detailed modeling methodologies.

d. Continue development of reduced-scale (physical) modeling.

C. Hazard Evaluation

Modeling methodologies which will combine toxicological and physiological models with testing to predict the "time available for evacuation" are needed. Such methodologies would take into account temperature, toxic gas concentrations, smoke density, heat flux, etc. Plans for the development of hazard evaluation methodologies, such as the current CFAC or combustion [illegible] have been initiated in the SAFER committee and will not be discussed here in detail.

D. Technical Working Group (TWG)

It is recommended that a technical working group be established to direct and coordinate the implementation of Phases 2 through 6 of this Plan. The TWG would be composed of representatives from government (FAA, NASA, NBS) and industry (airframe manufacturers, airlines) to insure that modeling technologies are developed with specific regard for user needs. This group would monitor progress, evaluate methodologies and make recommendations to achieve this goal.

PHASE 2: Applications Evaluation - Existing Technology

A. Assemble information on the capabilities of existing models and test facilities for model validation. In this regard, Figures 1 and 2 are provided as examples of information required to carry out this Phase.

B. Determine Capabilities and Limitations - Determine what existing models can or cannot predict for user application.

C. Evaluate Existing Test Facilities

(i) Large-Scale

a. Measurements - Assess relevance of measured quantities.

b. Scenarios - Determine applicable scenarios.

c. Test Methods - Assess procedures and measurement techniques.

d. Input/Output Evaluation - Evaluate test approach.

(ii) Small-Scale

a. Measurements - Assess relevance of measured quantities.

b. Test Methods - Assess procedures and measurement techniques.

c. Input/Output Evaluation - Evaluate test approach.

d. Full-Scale Application - Assess relevance to full-scale.

e. Utilization Aspects - Determine test apparatus availability and effort required.

D. Evaluate Existing Models

(i) Theoretical Application - Assess the methodologies employed in modeling physical and chemical phenomena.

(ii) Experimental Evaluation - Compare model predictions with experimental data.

(iii) Input/Output Evaluation - Evaluate modeling approach in terms of knowledge gained for a given set of inputs.

(iv) Utilization Aspects - Evaluate model availability, ease of implementation and computer requirements.

E. Obtain New Data

When necessary new test data and/or model results will be obtained to carry out this Phase. Figures 3 and 4 indicate, schematically, existing data and planned/potential new data which might be utilized for purposes of evaluation in Phase 2.

PHASE 3: Recommendations for Further Development and/or Refinement

A. Existing Models - Identify existing models for further development and refinement.

B. New Models - Determine what new models are required to meet objectives and requirements.

C. Large-Scale Testing - Identify large-scale test program needs for model applications.

D. Small-Scale Testing - Identify needs for new or modified, small-scale test methods.

E. Output - Identify modeling and testing methodologies which have immediate applications in terms of user needs. This may include: working models with specific applications, scaling relationships, empirical correlations and validation testing.

PHASE 4: Further Development and Refinement

A. Refine Existing Models identified for further development.

B. Develop a Detailed Fire Dynamic Model for the post-crash fire scenario.

C. Develop other new model(s) previously identified as necessary to meet objectives and requirements.

D. Develop or refine test capabilities as necessary to meet objectives and requirements.

PHASE 5: Applications Evaluation - Modified and New Methodologies

A. Assemble Information - As in Phase 2.

B. Determine Capabilities and Limitations - As in Phase 2.

C. Evaluate Test Facilities - As in Phase 2.

D. Evaluate Models - As in Phase 2.

PHASE 6: Identify Methodologies

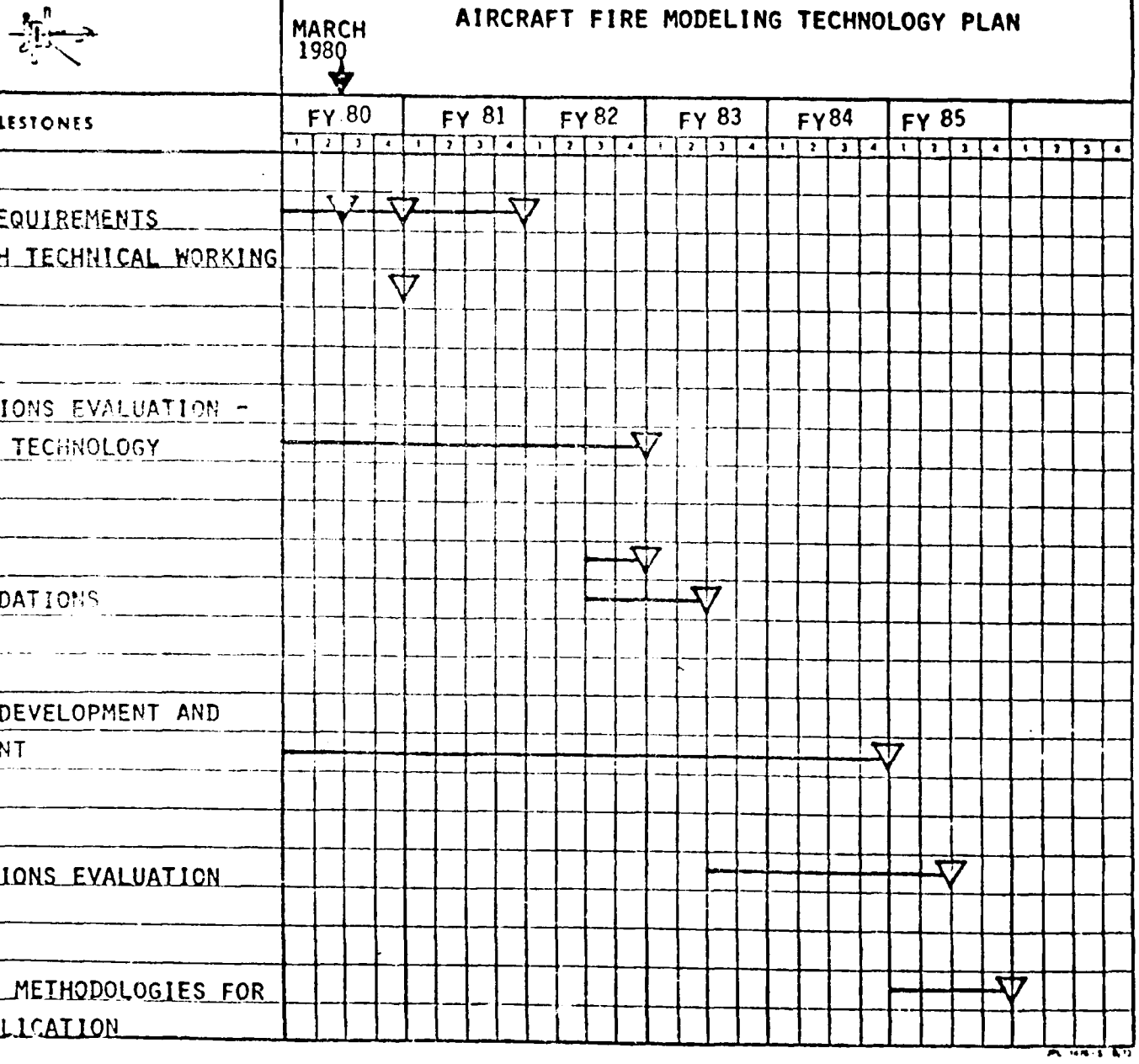
Appraise the status of fire modeling technology. Identify modeling methodologies which, when utilized with developed test methods, have definitive applications in terms of user needs. These methodologies should include: working models, scaling relationships, and empirical correlations; and small- and large-scale test methods.

V. Modeling, Testing and Design Interactions

During the entire Fire Modeling Technology program there should be close coupling and interactions between the activities associated with modeling, hazard evaluation, experimental/testing and existing aircraft design and design methods. This coupling is indicated schematically in the Plan Schematic on the back page; however many more interactions (vertical connectors) than those indicated should take place during the various phases of the program. Also, the establishment of the Technical Working Group is intended to assist in furthering these interactions.

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AIRCRAFT FIRE MODELING TECHNOLOGY PLAN



PHASE 2
EXISTING MODELING CAPABILITIES
(EXAMPLE)

	FIELD OR ZONE	CONSERVATION EQUATIONS					SURFACE IGNITION	COMBUSTION OF GASES	TURBULENCE	BOUNDARY CONDITIONS			RADIATION	PLUME MODEL	SPECIFIC DATA REQUIRED	PREDICTED QUANTITIES					
		MASS	MOM	ENERGY	GAS SPECIE	SVOOT				VENTILATION		SURFACES				P	r_g	T_s	$\bar{v}$	SMOKE	SPECIES
										NATURAL NO. OR FORCED OPENINGS											
FROM JPL	F 12-01	✓	✓	✓	✓	LATER	LATER	P	EFFECTIVE TRANSPORT PROPERTIES	FIN	2	NO-SLIP VELOCITY; HEAT TRANSFER TO SURFACES; GASIFICATION OF FUEL	✓	N/A	THERMOPHYSICAL AND THERMOCHEMICAL PROPERTIES, STOICHIOMETRY	✓	✓	✓	✓	LATER	✓
NOTRE DAME	F 12-01	✓	✓	✓					ALGEBRAIC MODEL (CORE AND WALL)	N	1,2	NO-SLIP VELOCITY; HEAT TRANSFER TO SURFACES	3-D MODEL: SOOT, H_2O, CO_2 BANDS	N/A	VARIOUS FUNDAMENTAL PHYSICAL PROPERTIES; SPECIE AND SOOT CONCENTRATION	✓	✓	?	✓		
MC DONNELL DOUGLAS	Z 01	✓		✓	UK		UK	SE		UK	UK	HEAT TRANSFER TO SURFACES	BLACK BODY?		UK		✓	✓			UK
DAYTON	Z 03	✓E	PLUME, CEILING JET ONLY	✓E	✓E	✓E	✓E	E		FIN	2	HEAT TRANSFER TO WALLS AND CEILING	ABSORBING AND EMITTING UPPER LAYER FLAME RADIATION MODEL INCLUDING SOOT	FANG/ROCKET FLAME/PLUME MODEL; STEWARD MODEL IN BUOYANT PLUME	RATES AND TIMES GOVERNING TRANSITION STATES; HEAT RELEASE, SPECIE EVOLUTION, FLAME SPREAD		✓	✓		✓	CO, CO2, HCN, HCl, SO2, NO
FITRI	Z 02	✓E		✓E			✓E	E		N	1	HEAT TRANSFER TO WALLS AND CEILING	BLACK BODY?	FANG'S FLAME/PLUME MODEL	FUEL GASIFICATION RATES, COMBUSTION EFFICIENCY		✓	✓			
NBS	Z 10	✓		✓				P		N	1	HEAT TRANSFER TO WALLS AND CEILING		STEWARD'S TURBULENT DIFFUSION BUOYANT PLUME MODEL	SOOT CONCENTRATION ΔH_c GASIFICATION TEMPS, STOICHIOMETRY						
HARVARD	Z 02	✓E		✓E				E		N	1	HEAT TRANSFER TO UPPER WALLS AND CEILING	?	MORTON'S "POINT-SOURCE" BUOYANT PLUME	BURNING RATES		✓	✓			

E - EMPIRICAL INPUT REQUIRED
SE - SEMI-EMPIRICAL
P - PREDICTED
NA - NOT APPLICABLE
UK - UNKNOWN

FIGURE 1

PHASE 2
EXISTING LARGE-SCALE TEST CAPABILITIES FOR MODEL VALIDATION (EXAMPLE)

ORGANIZATION/ FACILITIES	SCENARIOS							MEASUREMENTS				
	EXTERNAL FUSELAGE FIRE				CABIN FIRE		POOL FIRES	TEMP.	GAS ANALYSIS	SMOKE	HEAT FLUX	GAS VELOCITY
		SIZE	LOCATION	WIND		VENT.						
NAFEC C-133	✓	✓	✓	NO	✓	?		✓	✓	✓	✓	
NASA/JSC	P →				✓	F, N	✓	✓	✓	✓	✓	✓
BOEING					✓	F		✓	✓	✓	✓	✓
MACDAC					✓	F		✓	✓	✓	✓	
NASA/AMES							✓	✓	✓		✓	

P = POTENTIAL CAPABILITY
F = FORCED VENTILATION
N = NATURAL VENTILATION

FIGURE 2

PHASE 2
APPLICATIONS EVALUATION:
EXISTING DATA

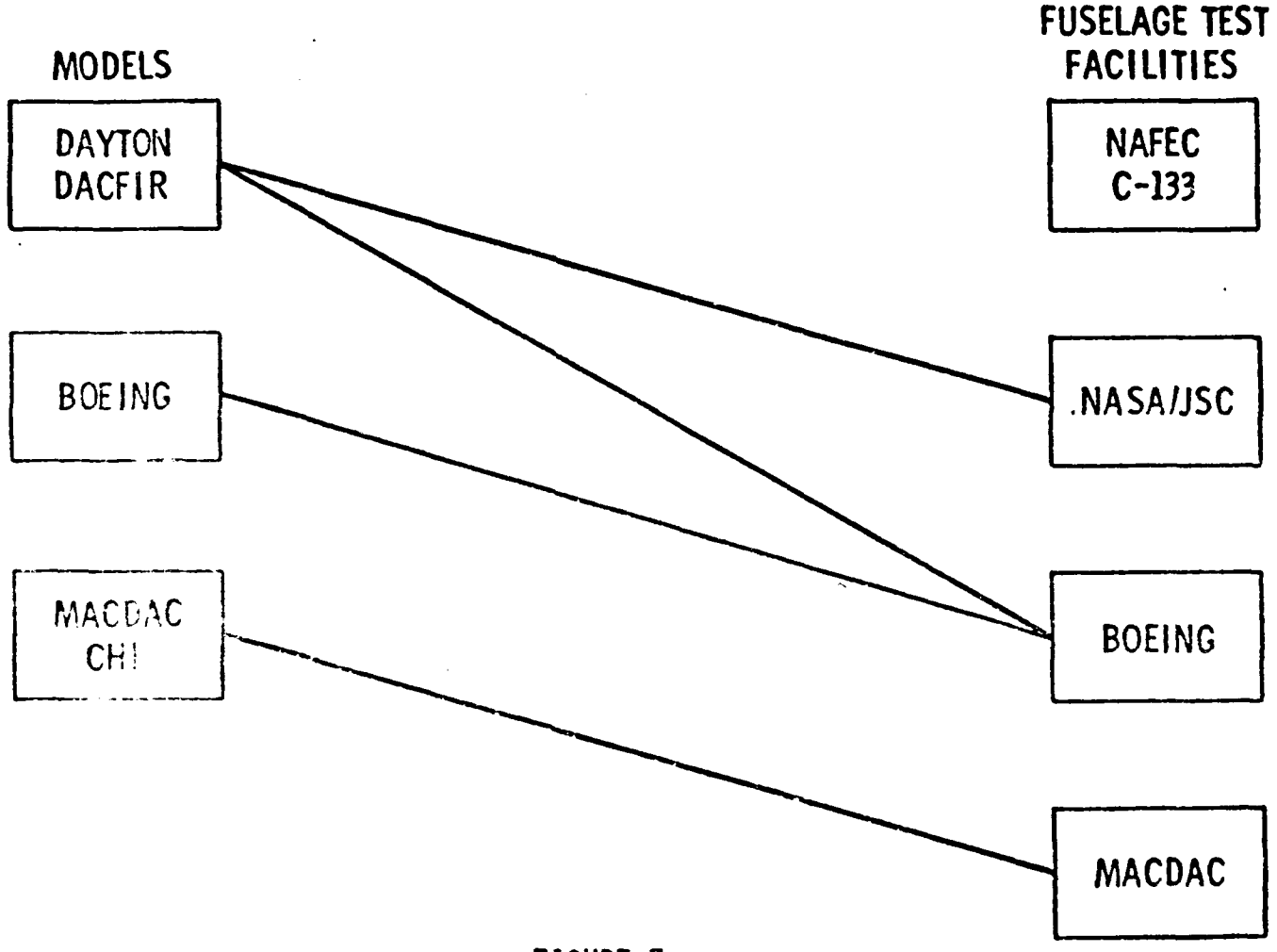


FIGURE 3

PHASE 2
APPLICATIONS EVALUATION: PLANNED AND POTENTIAL NEW DATA

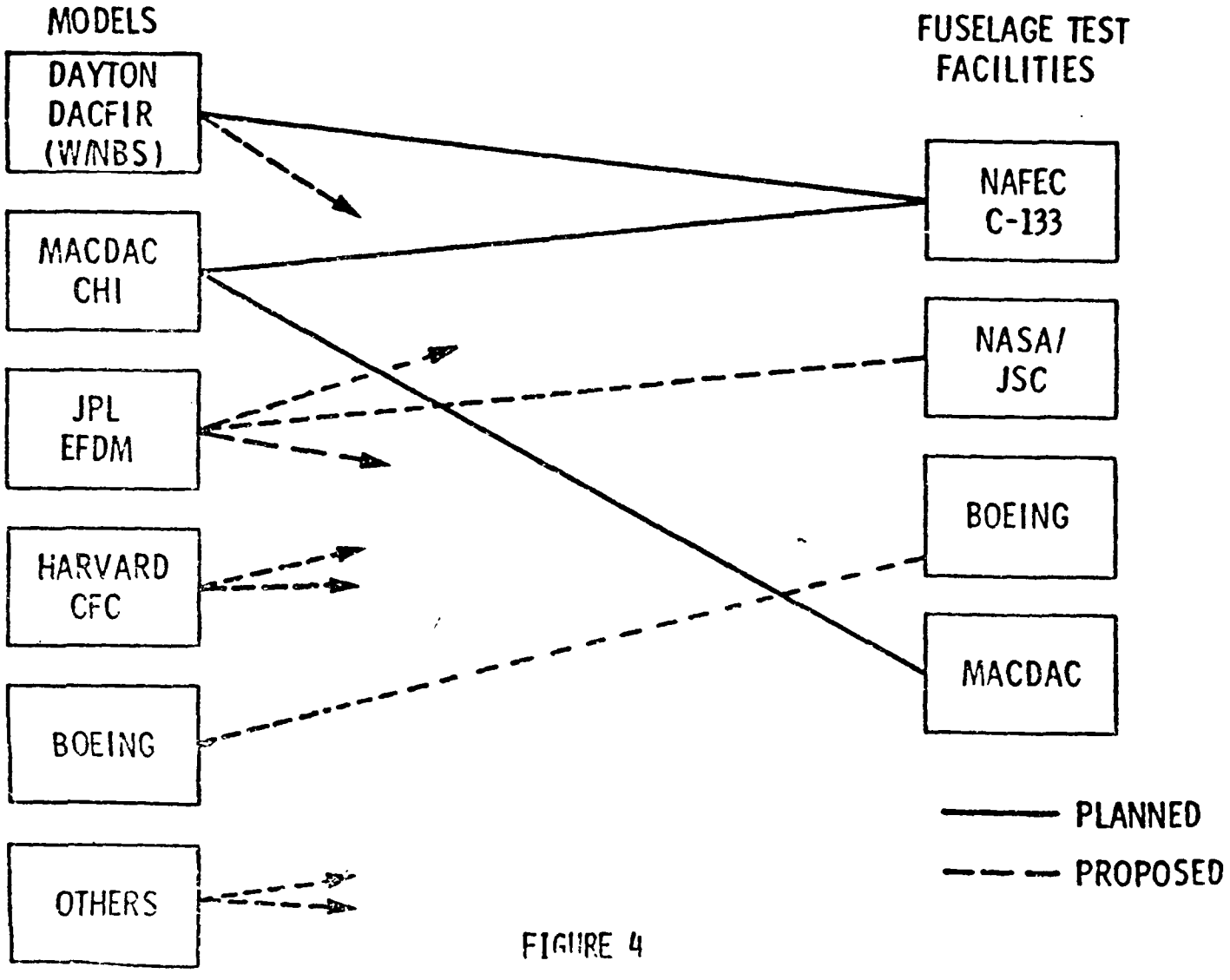


FIGURE 4

APPENDIX

FIRE MODELING TECHNOLOGY REQUIREMENTS

SUMMARY OF INPUT

AIRCRAFT FIRE MODELING TECHNOLOGY PLAN
DEFINITION OF REQUIREMENTS
SUMMARY OF INPUT

- NEED BROAD MODELING METHODOLOGY FOR DESIGN EVALUATION. (DOUGLAS, LOCKHEED, BOEING)
- DESIGNER NEEDS TO RUN SENSITIVITY OR PARAMETRIC ANALYSIS FOR END DESIGN CONFIRMATION. (DOUGLAS, LOCKHEED, BOEING)
  - DIFFERENT TYPES MATERIALS
  - LOCATION
  - ORIENTATION
  - VENTILATION RATES
  - GEOMETRIES
  - FIRE BARRIERS
  - COMPARTMENTATION
- MODELING NEEDED TO EXTRAPOLATE SMALL-SCALE TESTS TO FULL SCALE.
  - SMALL SCALE TESTS CANNOT BE DIRECTLY RELATED TO IMPROVEMENTS IN PASSENGER SAFETY. (DOUGLAS)
- MODELS NEED TO CONSIDER: (DOUGLAS, LOCKHEED, BOEING)
  - SMOKE (VISIBILITY)
  - TOXIC GASES
  - TEMPERATURE
  - FIRE PROPAGATION
  - HEAT FLUX
  - FLASH FIRE/FLASHOVER
- MODELS MUST BE VERIFIED IN FULL-SCALE TESTS. (LOCKHEED, BOEING)
- STANDARD SMALL-SCALE TEST METHODS NEEDED FOR EVALUATION OF MATERIAL PERFORMANCE
  - ESTABLISH ACCEPTANCE CRITERIA (PRESENT CRITERIA ARE RELATIVELY ARBITRARY). (DOUGLAS, LOCKHEED, NAFEC)
- MODEL INPUT MUST BE REALISTIC AND READILY OBTAINABLE (FROM TEST DATA); OUTPUT MUST BE IN A USABLE FORM. (LOCKHEED, BOEING)
- NEW FLAME SPREAD TEST MEASUREMENT IS NEEDED. (LOCKHEED)



DEFINITION OF REQUIREMENTS

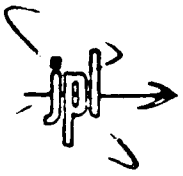
SUMMARY OF INPUT

(CONTINUED)

- MODELING NOT SIGNIFICANTLY UTILIZED NOW IN THE DESIGN PROCESS. (LOCKHEED)
- A LIMITED NUMBER OF SCENARIO(S) MUST BE ESTABLISHED FOR CERTIFICATION. (BOEING, NAFEC, AMES)
- EMPHASIZE EXTERNAL FUEL FIRE AND RESPONSE OF INTERIOR MATERIALS TO THIS FIRE THROUGH AN OPENING. (DOUGLAS, LOCKHEED, BOEING, AMES, NAFEC)
- EXPERIMENTAL NEEDS INSTRUMENTATION IMPROVEMENTS (DOUGLAS) -

  VELOCITY MEASUREMENTS
  SIMPLIFIED GAS ANALYSIS
  ESTABLISH SAMPLING VALIDITY
  MODELING CAN ASSIST IN INSTRUMENTATION PLANNING

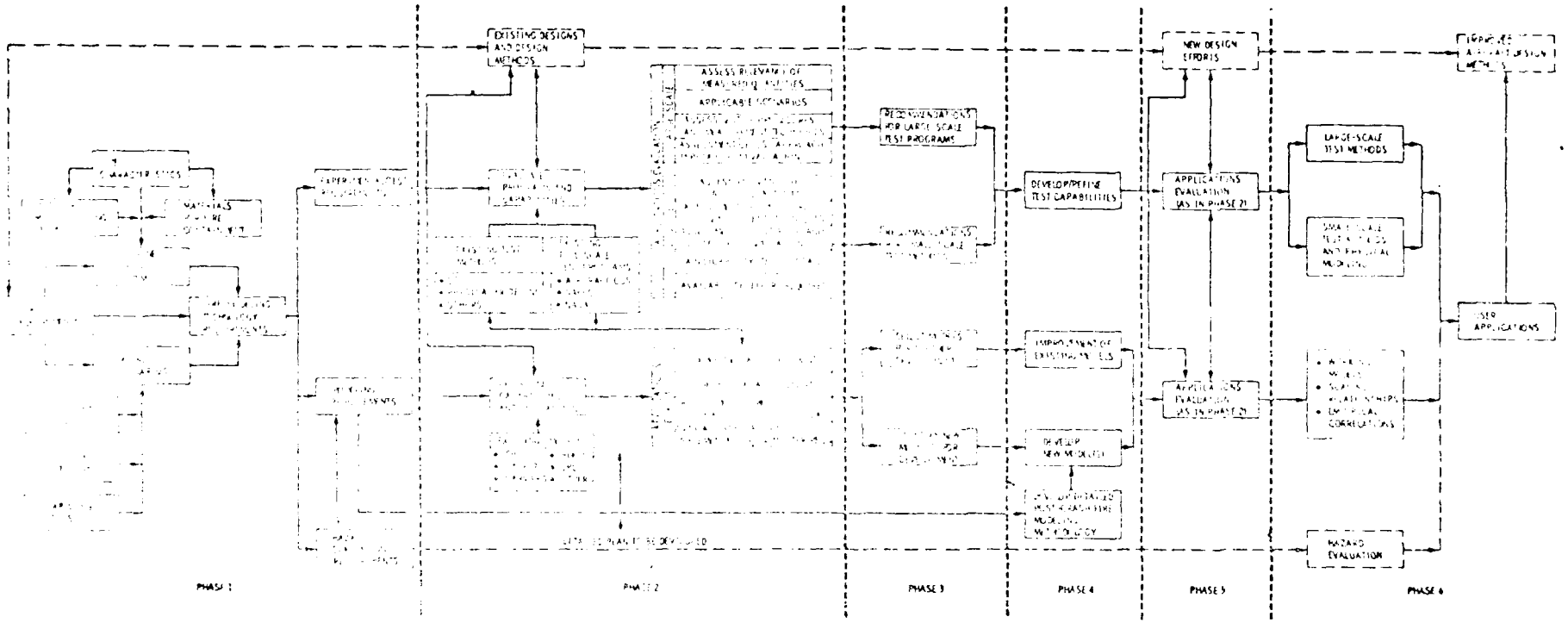
- APPROPRIATE FIRE SOURCES MUST BE SPECIFIED FOR SMALL-SCALE TESTS. (DOUGLAS, LOCKHEED, NAFEC)
- COST, WEIGHT, AVAILABILITY, PROCESSABILITY, STRENGTH, DURABILITY, CUSTOMER ACCEPTANCE MUST ALSO EVENTUALLY BE CONSIDERED IN FINAL DESIGN EVALUATION. (LOCKHEED, AMES)
- NEED TO MODEL TIME AVAILABLE FOR PASSENGER EVACUATION OR "SAFETY," EVALUATE (QUANTITATIVELY) HAZARD. (DOUGLAS, LOCKHEED, BOEING, AMES, NAFEC)
- PASSENGER CARRY-ON ITEMS AND/OR AIRLINE ACCESSORIES SHOULD BE CONSIDERED IN SCENARIO. (LOCKHEED, NAFEC)



DEFINITION OF REQUIREMENTS
SUMMARY OF INPUT
(CONTINUED)

- OUTPUTS FROM THE PROPOSED PLAN SHOULD BE SPECIFIED WITH REGARD FOR FAA TIME FRAME (2-4 YEARS). (NAFEC, AMES)
- SPECIFY MODE FOR EXCHANGES OF INFORMATION AMONG MODELERS, EXPERIMENTALISTS AND DESIGNERS. (DOUGLAS, BOEING)
- NEED AIRLINE INVOLVEMENT SINCE THEY ARE RESPONSIBLE FOR AIRCRAFT REFURBISHMENT. (LOCKHEED)
- A CONCENSUS (INDUSTRY, FAA, NASA) SHOULD BE REACHED ON SUCH REQUIREMENTS AS SCENARIOS, TEST CRITERIA, ETC.; AS THESE ISSUES ARISE DURING THE CONDUCT OF THIS PLAN. (DOUGLAS, BOEING)

AIRCRAFT FIRE MODELING TECHNOLOGY PLAN



5.0 Testing

As discussed in the foregoing, much of the activity in testing involves standardized laboratory testing and large scale tests for empirical predictive purposes. As these are covered in detail in other sections of this report as well as outside of this R&D sub-group, only a few summary observations are made here.

At the Subgroup R&D Review Meeting held August 13-14, 1979, several conclusions were reached regarding full-scale and laboratory testing of aircraft cabin materials. These were as follows:

1. Full-scale and mockup testing are required because there is a lack of reliable predictive methods.
2. Laboratory and full-scale test correlation with accident performance needs extensive development.
3. Correlation of laboratory tests with full-scale tests requires further effort.

The recommendations of the subgroup are the following:

1. Continue C133 full-scale tests at NAFEC. These tests should utilize an agreed upon fire scenario and be completed in approximately 2 years. Additionally, the test program should include advanced material tests after testing of contemporary materials is completed.

2. Mockup test configurations should be defined and the validity verified. This type of test is less expensive to conduct and provides more rapid turn-around times.

3. Further effort should be expanded to correlate laboratory tests with full-scale and mockup tests. The Ohio State Apparatus shows promise of providing correlation with additional work. Laboratory methods for measuring toxic gases do not currently correlate with full-scale test results and require further work. Part of this effort should be conducted as an ASTM activity after the tests are proven to be valid indicators for at least ranking the various materials regarding their relative hazards.

6.0 Toxicity

The relative significance or insignificance of a toxicological risk or hazard associated with the evolution of toxic combustion products from cabin materials during a post-crash fire as compared to the hazard of heat and flames has not been established.

The determination of the "overall" hazard (smoke, heat, toxicity, flame spread, etc) and the significance of each factor relative to escape will require considerable research and should be supported.

While recognizing the complexity of the hazard assessment problem, and that the significance of each factor is unknown, it is clear that a toxicity hazard research program is required to assess the combustion product toxicity problem. In fact, the proposed program interfaces directly with cabin design (mathematical modeling) which may provide insights into the significance of the various factors that contribute to the overall hazard. In any event, it is recognized that the following proposed toxicity research program presented below may not be the limiting factor in post-crash survival and escape from a burning aircraft.

The proposed toxicity program was developed around 4 tasks. They are:

1. Fire scenarios,
2. Time of exposure, incapacitation and post-crash effects,
3. Toxicity data and cabin design, and
4. Relationship of data obtained on rodents to human response.

The following program addresses the tasks in sequence as listed. However, it should be noted that the last 3 tasks and proposed programs are <u>not</u> independent of one another and in fact some of

the tasks appear more than once. Dates are listed for completion of the various phases or tasks. Meeting these milestones is obviously dependent on resource availability and priority given them by various federal agencies and as such are subject to change.

6.1 Fire Scenarios

Very little time was spent on the selection of a most probable fire scenario or scenarios since this is described above in Section 3.0 on Criteria for Design. However, it should be recognized that the selection of a scenario will have an influence on the combustion source used to generate combustion products and perhaps the type and degree of toxicity obtained. As a result, research needs are listed under the scenario task that are relevant to the combustion model.

From a combustion toxicology perspective, the objective of the scenario group is to specify a post-crash fire scenario in order to design a relevant combustion model for assessing the combustion of cabin materials. Selection of a most probable scenario is critical since there are many possible fire conditions.

From a review of the state-of-the-art on combustion product toxicology hardware for generation of degradation products, it would be desireable to develop a radiant heat source load cell system that is compatible with an animal exposure model that

is representative of the desired scenario. Such a system would provide a surface radiant exposure that a cabin material might experience during a fire and simultaneously provide the amount of material degraded for expressing the dose of toxic products to which the animals are exposed. The system must also provide the flexibility of doing flaming and non-flaming decomposition of a broad range of materials (thermo plastics, char formers, composites, etc.). Such a system would need to be validated with large scale fire analytical and toxicological experiments. These large scale experiments should be used for mathematical model research discussed later (issue 3). Chemical analysis for quantitative measurement of species should be included.

It is estimated that the development of a radiant heat system compatible with an animal model could be done by the end of 1981 and the large scale validation by mid 1983.

6.2 Time-Exposure, Incapacitation and Post-Exposure Effects

The objective of this task is to develop an incapacitation model that is relevant to escape potential. The animal model should also be predictive of post-exposure physiological damage although this was not given a high priority.

The time-exposure period equivalent to escape time from an aircraft of 2 minutes is unrealistic for animal toxicity studies. Such short exposure periods will result in data with a great deal of scatter due to respiratory rate changes, concentration

variability, etc. Consequently, exposure times of at least 15 minutes and preferably 30 minutes will have to be used and the results extrapolated back to time intervals of interest

The state-of-art in animal incapacitation models for use in combustion product toxicology is limited to rodents. The relationship of these models to human ability to escape from the fire scene is poorly understood if at all (see task 3, section 6.4). Secondly the models provide little additional information that is not obtained from lethality measurements. Thirdly, the relevance of the models to the broad range of toxic product produced in the fire environment is unknown. For example, the relevance of rodent (obligatory nose breathers) toxicity data for the acid gases to human response is very questionable based on recent experience. To resolve these questions, three studies are proposed.

1. develop time-concentration effect curves for longer than 2 minute time periods and extrapolate to shorter times and respective toxic gas concentrations. This includes doing pure gas studies as a function of time and concentration. Development of mathematical models of time-concentration effect curves will allow this to be done with reasonable confidence. It is anticipated that the experiments necessary for developing such a model could be completed by mid 1984.

2. develop a broader based program on escape models using different animal species. A detailed analysis of existing incapacitating models and behavioral toxicology is a first step toward a resolution of this issue. This is most likely a 5 year project-complete by end of 1985.

3. develop acid gas toxicity data on non-rodent animal species to determine the hazard due to acid gases and the relevance of rodent data. This may require a non-lethal primate study (section 6.4). This could be completed by 1984.

Acid gases are emphasized due to the fact: (1) it appears that rodents tolerate high concentrations of such gases, (2) rodents represent an animal model not comparable to humans and (3) many of the polymers for aircraft applications give off acid gases.

6.3 Toxicity Data and Cabin Design

The objective is to develop the methodology for assessing the fire hazard or risk for a given cabin design that takes into account ignitability, flame spread, heat release toxicity, smoke, etc.

In the past a test method has been developed for the fire performance of each part of the problem. This includes ignitability, flame spread, etc. No method has been developed

to assess the overall hazard or relative importance of each factor. Similarly, the use of toxicity data on various materials and rank ordering of these materials from least toxic to most toxic may be inappropriate as a means for selecting materials. The question is how does one incorporate toxicity data into risk and fire modeling? Large scale fire toxicity measurements, for example, are of limited value, expensive and in most cases difficult to interpret. Heat stress may be the most significant factor in such tests especially if rodents are the animal of choice.

The research program suggested for reaching this objective consists of 3 steps:

1. develop toxicity data on various materials and pure gases in small scale,
2. develop methematical models that utilize data in step 1 above and
3. design large scale experiments to validate the model.

In step 1 toxicity information includes the identification of primary toxicant(s), concentration or yield of primary toxicological results must be verified with pure gas studies.

The second and third step could perhaps be combined based on the state-of-the-art in mathematical modeling. This requires the design of large scale fire experiments with appropriate

measurement of temperature or heat flux and rate of generation or time-concentration of primary toxicant(s) on materials evaluated in step 1. After analytical validation of the model, animal exposures would be needed as final verifications. This would require about 6 years, and perhaps could be completed for selected materials-cabin design-fire scenarios by end of 1986.

6.4 Relationship of Data Obtained on Rodents to Human Response

The objective of this task is to develop toxicological data that is relevant to human response. It should be recognized that other fields of toxicological research rely heavily on animal data and in many cases on rodent data. However, it should also be noted that many of these areas of toxicology follow-up or develop human data either directly or through epidemological studies. This is not to suggest that human studies be done but to emphasize the need for caution. However, every available effort should be made to carryout good post-mortem studies on crash fire victims.

There are 2 parts to the toxicological problem or two modes of incapacitation. They are through adverse physiological effects and through adverse behavioral effects. The physiological effects are monitored by measurements of EKG, EEG, COHb, respiratory function, motor incapacitation, etc. Furthermore, physiological measurements on rats are likely to be fairly predictive of

human physiological response to combustion product toxicity. Even if the animal of choice is different, the physiological response can be approximated by relative mass relationships. It is suggested, however, that the pulmonary irritants, especially the acid gases may be an exception due predominately to the difference in respiratory physiology. That is, a human is likely to breath through his mouth in the presence of acid gases.

Behavioral effects that interupt rational thought processes could occur at sublethal, subphysiological effect levels that may also prevent escape. The rodent models are likely to provide little if any insights into this problem.

It is proposed that any animal model may be developed to address the escape potential rather than incapacitation. This could be a rodent model but is limited to physiological aspects of the problem.

The behavioral aspects should be studies with a sublethal primate program. This program must be well defined, designed to answer specific questions regarding behavior.

Both parts of this task could be completed by the end of 1985.

ENCLOSURE 1

ATTENDANCE AT SAFER MEETING ON

COMPARTMENT MATERIALS R&D

AUG 13-14, 1979

MEMBERS

E. Bara	-	Boeing
R. Bricker	-	NASA, JSC
S. Davis	-	NBS (absent)
J. Fargo	-	Lockheed
R. Kirsch	-	FAA, HQ
R. Landel	-	JPL
J. Parker	-	NASA, AMES
M. Salkind	-	NASA, HQ
C. Sarkos	-	FAA, NAFEC
H. Schjelderup	-	Douglas
S. Weiss	-	NASA, HQ
M. Wilfert	-	Douglas

VISTORS

E. Fasig	-	DuPont
D. Kourtides	-	NASA, AMES
A. Heimbuch	-	NASA, AMES
G. Nelson	-	GE
K. Ramohali	-	JPL
J. Sahakiam	-	JPL
J. Bellan	-	JPL
P. Bankston	-	JPL
L. Back	-	JPL
R. Anderson	-	Boeing
L. Fewell	-	NASA, AMES
H. Branting	-	FAA
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2/28/80

DRAFT -

REPORT OF THE AIRCRAFT ACCIDENT STATISTICS SUB-GROUP

Introduction

At the June 1979 meeting of the SAFER Technical Group on Compartment Interior Materials, a sub-group was created to review aircraft accident statistics as they relate to survivable post-crash fires (hereinafter referred to as fires). This sub-group was charged to study fatality statistics, to up-date the pertinent service record, and to develop the scenarios by which people die in fires.

During the months following, an effort was made to identify those incidents which fell within the scope of this technical group. By written communication, the sub-group provided some feed-back as to proper identification of incidents and probable sequence of events. This resulted in a list of aircraft accidents involving fire in which there were survivors and fatalities. This list was circulated to the sub-group prior to the meeting held on February 21, 1980 (see attached attendance list).

Although this sub-group was charged with studying statistics, at the outset it was apparent that statistics pertained to numbers and percentages and, until scenarios could be defined, the impact of changing cabin interior materials could not be assessed. Therefore, the only direction in which the sub-group could move was to review available data (incident reports) and attempt to develop the scenarios.

The boundaries within which this review was to be made were defined as follows:

U.S. carriers
Jet-type aircraft
Commercial or charter
Passenger carrying
Survivable crashes involving fire
Cabin interior materials

It would be expected that the benefits gained from the SAFER activities would impact on those areas of air transport outside these boundaries.

Review of available data

Most of the data examined within the boundaries defined above involve accidents with aircraft certified prior to the current FAR 25.853 requirements imposed in 1968; it must be remembered that FAR 25.853 is a flammability requirement applicable only to aircraft cabin interior materials. The data reporting systems currently in use do not differentiate between fuel and material fires; however, the implication is that a fuel fire was always present.

Data reporting does not provide information needed to make a determination of the number of post-crash fire-related fatalities. As a consequence, it is not possible to make a determination of the number of fatalities due to the fuel fire or due to a fire involving cabin interior materials, to say nothing of carry-on materials.

Even though the cause of death, exclusive of impact or burns, may be identified (asphyxia or inhalation of superheated air), it is not possible to identify the source of the toxic gases or superheated air. Where post-mortem examinations have been made, there have been disagreements among pathologists as to the cause of death. To further complicate matters, the pathologists are usually not aware of the extent of impact damage. In addition, the National Transportation Safety Board investigating team must rely on local medical examiners and has no control over the quality of these people.

An attempt was made to determine the most usual scenario(s) based on the data available. It could only be concluded that there was no common scenario defined for survivable post-crash fire incidents except that there was an intense fuel fire. The sequence of events differed in every accident and the factors affecting the outcome of an accident varied from incident to incident with no common thread. To support the contention that it is practically impossible to define scenarios, the sub-group attempted to list some of the variables which determine the outcome of an accident.

Where the fire started
When the fire started
Propagation - direction, rate
Wind - direction, velocity
Weather - temperature, dew point, precipitation
Fuel-type, amount, location
Fuel spill - slow, pool, amount
Fuel misting/vaporization
Speed at time of impact (survivable)
Attitude of aircraft upon impact
Terrain - mud, rocks, water
Obstacles struck - buildings, other aircraft
Number and location of openings - exits, breaks
Type of aircraft - wide body, narrow body
Engines - wing pod, aft body mounted
Cargo - type, quantity
Number of passengers
Passenger make-up - handicapped, aged
Number of crew
Training and response of crew

Even though it may be possible to identify most or all of the above variables, the number of possible combinations would be astronomical. The in-depth analysis of the available data would take more time than is available to the SAFER committee and would probably not provide the desired information.

As a result of information obtained from previous incidents, the air transport industry has made improvements in design and in operating procedures to eliminate the presumed cause of the incident and the Federal Aviation Administration has made changes in regulations requiring the air frame manufacturers to make changes or modifications in design. It is intuitive that improved cabin interior materials would reduce fire fatalities; however, this sub-group cannot attempt to define the needed improvement nor can it provide an estimate of the degree of reduction in fatalities which would be expected.

Conclusions

1) "Statistics" cannot be used as a basis for making determinations for design changes in aircraft.

2) There are gaps in the data which have been collected; the state-of-the-art has not enabled some of these gaps to be filled.

3) There are insufficient resources to thoroughly investigate each accident by having all areas of expertise as part of the investigating team. At the time of investigation it is not always possible to determine the sequence of events leading to fatalities.

4) There has been a lack of pertinent data on survivability as it relates to fire and the available data are not readily retrievable, which could facilitate more thorough analysis of the incident.

5) Fuel has been invariably involved in incidents in which there were fatalities.

Recommendations

1) There needs to be an improvement in data gathering. The AIA and FAA should be requested to work with NTSB to develop a more thorough standardized investigative report format. There should be a continuing procedure to review and up-date the data collection process. Concomitently, there should be an improved data retrieval system to make the data available to more people.

2) Existing data should be more thoroughly investigated, vis-a-vis the NASA study.

3) Future changes in design and in regulations should be based on more complete data garnering and analysis.

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Report Of The SAFER Technical Group

On

Post-Crash Fire Hazard Reduction

Presented to the SAFER Advisory Committee at NASA Ames Research Center, 9-27-79

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I. Summary

Several methods for reducing the fire hazard in a post-crash environment were reviewed to determine their feasibility and potential for improving passenger survivability. These methods included explosion suppression systems, fuel tank foam or foil, fuel tank inerting, crash-resistant fuel tanks, and anti-misting fuels. None of these methods, at their present state of development, are feasible for commercial aircraft application or offer significant advantages over present methods of protection such as vent flame arrestors and assured cutoff of the fuel supply to the engine in emergencies.

Further development of fuel tank inerting methods is encouraged to reduce complexity and weight and improve reliability of the system.

Anticipated FAA/NASA programs to investigate factors to be considered to improve the crashworthiness of aircraft is expected to include the use of crash-resistant fuel tanks. At the present time they appear to be feasible in fuselage cargo compartments only.

Anti-misting fuels appear to hold the most promise for increasing passenger survivability by reducing the fuel fire hazard in the post-crash environment. However, much development testing is required before its feasibility can be established.

The state of development of the above systems is not sufficient at this time to warrant modifying regulations which would require their incorporation. However, it is suggested that the FAA consider modifications to the regulations requiring the inclusion of fuel tank vent protection from ground ignition sources and assurance of engine fuel supply cutoff in emergency situations.

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II. Introduction

The Technical Group on Post-crash Fire Hazard Reduction was formed by the SAFER Committee in May 1979 and was assigned the task of investigating means of reducing the fuel fire hazard for transport category airplanes in a survivable post-crash environment. The assignment included an evaluation of state of the art technology for existing and completed research and development programs in terms of their contribution to airplane safety. Based upon this evaluation, the group was asked to determine:

1. If completed R&D program results warrant rule making action or the publication of guidance material;
2. If existing programs should be continued, redirected, or aborted; and
3. If new R&D programs should be initiated.

To implement this task, experts from a broad group of government and industry organizations were invited to participate. Approximately 50 people representing airframe manufacturers, airline operations, government agencies, and equipment suppliers were included (Appendix A).

The group held its first meeting at NAFEC headquarters in Atlantic City, New Jersey in June 1979. Various means for reducing the fuel fire hazard were proposed and discussed. These could be categorized as:

1. Methods of eliminating fires inside fuel tanks (e.g., inerting the vapor space, installing reticulated foam or expanded metal foil, and explosion suppression), and
2. Methods of eliminating or reducing the probability of external fuel fires (e.g., fuel containment and anti-misting additives in fuels.)

Since these concepts represent a wide range of specialized solutions, the task was broken down into more closely related subjects and assigned to the following sub-groups (Appendix B):

1. Explosion Suppression, Fuel Tank Foam/Foil, and Fuel Tank Inerting Chairman H. Skavdahl
2. Crash-Resistant Fuel Tanks - Chairman J. F. Wignot
3. Anti-misting Fuels - Chairman A. T. Peacock

This summary report represents the results of their efforts and has been approved by a majority vote of the technical group.

III. Explosion Suppression, Fuel Tank Foam/Foil and Fuel Tank Inerting (Reference 1)

Fuel tank fires can be prevented if the oxygen concentration in the vapor space above the fuel is maintained below combustible limits. Nitrogen purging of the fuel and vapor space can be an effective means of accomplishing this effect. Such a system is currently installed on all C5A airplanes. However, the system involves a complex network of valves, pressure regulators and cryogenically stored nitrogen which represents a significant weight and economic penalty to the airplane. The problems of storing sufficient cryogenic nitrogen for a complete flight plan may be alleviated by an on-board nitrogen gas generation system such as is currently under development. However, this system is heavy and must undergo much more development testing before its viability for production installations can be considered.

An alternative to fuel tank inerting is the installation of heat reticulated foam or expanded metal foil in the fuel tanks. These systems have the advantage of being passive. They prevent excessive overpressures from developing and eventually completely extinguish any fires that are generated within the tank. Foams are currently being used effectively in many military aircraft used in close support of combat troops where small arms incendiary projectiles are a constant threat. For civilian aircraft it is difficult to justify the severe weight penalties, impaired normal fuel tank maintenance activities, and additional maintenance problems created by foam shredding and enhanced bacterial growth probabilities in water accumulations at the tank bottoms.

Much of the foam discussion also applies to expanded metal foils in fuel tanks. Foils do have the advantage of a significantly higher melting point in a fire environment (1100°F compared to 360°F for foams). However, they are semi-rigid and present complex structural design problems which must be resolved in order to permit access to fuel tank components for service and maintenance.

Explosion suppression systems are used in some fuel tank applications where the tank geometry is relatively simple and direct communication to a detector element is available. The basic concept for this system is to sense the flame of an incipient explosion by an infrared or ultraviolet light detector and discharge a fire extinguishing agent to quench the fire before a hazardous overpressure can develop. However, numerous studies of the multi-celled fuel tanks in today's transports have shown that the complexity of the installation overrides its potential value because of the numerous detectors and suppressors required.

The above methods for preventing tank fires will be ineffective in accidents where major fuel tank rupture has occurred. In such cases, the major hazard is the external pool of burning fuel. Some degree of protection would be provided where minor damage occurs. However, the attendant external fire would be far less severe in that situation. In such circumstances, equivalent protection can be provided by a simple flame arrestor installed in the fuel tank vent line to preclude propagation of flame down the vent and by systems which ensure that engine fuel is shut off in fire emergencies. Direct ignition of vapors in the tank by conduction of heat through the tank wall is unlikely for small fires inasmuch as the vapor space oxidation rate is too low to become self-propagating. Tests at NAFEC have shown that this condition can result in the tank self-inerting as the oxygen is consumed by the slow oxidation process.

The above systems were evaluated in terms of weight, cost, maintenance, reliability, retrofit capability, and effectiveness. The results of this evaluation are shown in Figure 1. In every category the incorporation of a flame arrestor and assumed emergency fuel shutoff to the engines is rated as better than, or equivalent to, the more complex systems currently under discussion. Of the more complex systems, only the inerting system appears to offer some improvement in the post-crash fire environment. Figure 2 shows an assessment of the potential benefits that might have accrued if inerting systems had been incorporated in commercial jet transports since their inception. Of the 13 accidents involving post-crash fires, tank

ELIMINATION OF FIRES INSIDE FUEL TANKS

SUMMARY EVALUATION OF CONCEPTS

CONCEPT	WEIGHT	COST	MAINTENANCE	RELIABILITY	RETROFIT CAPABILITY	EFFECTIVENESS
LN_2	HIGH	HIGH	MODERATE	SATISFACTORY IN MILITARY SERVICE	EXTREMELY DIFFICULT	GOOD IF TANK NOT INITIALLY DAMAGED
GN_2	HIGH	HIGH	MODERATE - HIGH	NOT EVALUATED	EXTREMELY DIFFICULT	NOT EVALUATED
FOAM	HIGH	NOT KNOWN	HIGH	SATISFACTORY IN MILITARY SERVICE W / DEVELOPMENT	EXTREMELY DIFFICULT	NOT EVALUATED
[illegible]	HIGH	NOT KNOWN	HIGH	NOT EVALUATED	NOT POSSIBLE	GOOD FOR INTACT TANKS
TANK SUPPRESSION SYSTEM	MODERATE	MODERATE	HIGH	NOT EVALUATED	EXTREMELY DIFFICULT	NOT EVALUATED
VENT FLAME ARRESTOR	LOW	LOW	LOW	GOOD	YES	GOOD
EMERGENCY FUEL SHUTOFF	LOW	LOW	LOW	GOOD	YES	GOOD

Figure 1

TANK EXPLOSION ACCIDENT ASSESSMENT
(POST CRASH FIRES)

	FUEL / HULL LOSS / SURVIVORS / FATALITIES / YEAR / MODEL							POTENTIAL REDUCED FATALITIES OR HULL DAMAGE			LOW PROBABILITY OF ANY SYSTEM BENEFIT
								VENT ARRESTER OR SURGE SUPPRESSOR	IMPROVED FUEL CUTOFF	TANK INERTING	
GROUND	ROME	707	1964	49	25	Y	JP-4	X		X	
TOP-MOUNT	LONDON	707	1968	5	121	Y	KERO.		X	X	
WING	SINGAPORE	CMT	1964	0	68	Y	?	X			
DAMAGE	STOCKTON	DC-8	1979	0	4	Y	?		X	X	
	ATHENS	DC-8	1970	87	15	Y	KERO.				X
GROUND	[illegible]	DC-8	1967	21	39	Y	?				X
FIRE	CINCINNATI	880	1979	70	12	Y	KERO.				X
	CINCINNATI	727	1967	58	4	Y	KERO.				X
WING TANK	ST. THOMAS	727	1970	2	51	Y	KERO.				X
BREAK-UP	PAGO PAGO	707	1974	97	4	Y	KERO.				X
-SEVERE	NAIROBI	747	1974	59	97	Y	KERO.				X
BODY	TENERIFE	747	1977	335	61	Y	KERO.				X
DAMAGE	NEW HOPE	DC-9	1977	62	23	Y	KERO.				X

Figure 2

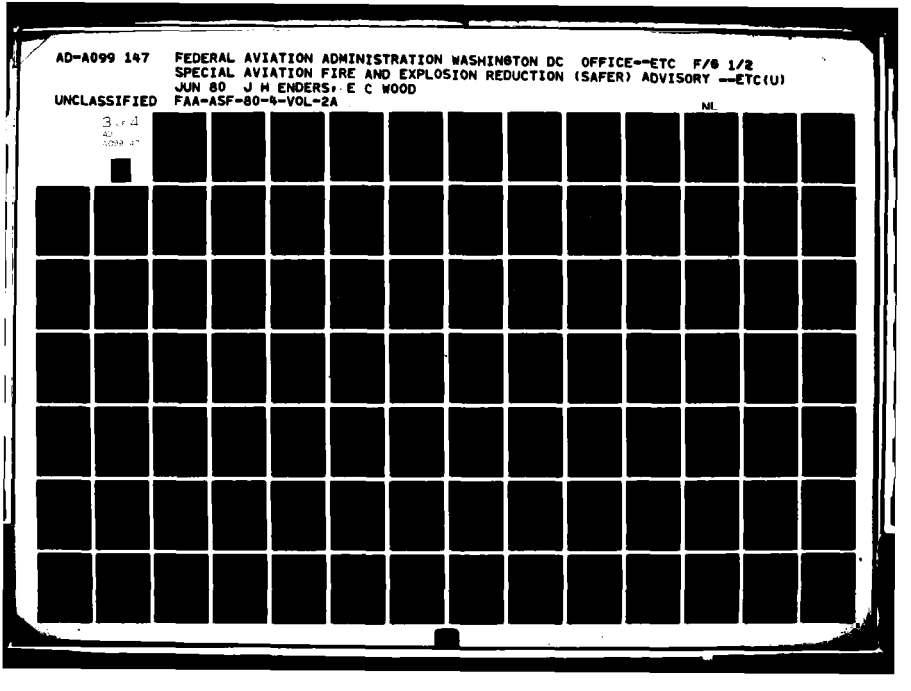
inerting had the potential of reducing fatalities or hull damage in only four cases. In each of these four cases, the relatively simple approach of vent flame arrestor or suppressor and improved methods of fuel cutoff in the engine feed line was determined to be as effective as the inerting system.

These simple and reliable systems are presently installed in most commercial transports. They are typical of the tried and proven fire protection designs which the aircraft industry has pursued throughout its history. Since 1958, this policy in jet transport design has resulted in a reduction in accidents involving fuel vapor explosions from 1.4 to approximately 0.1 per million departures (Figure 5).

From the above survey of existing and proposed ways to eliminate fires inside of jet transport fuel tanks, the group concluded the following:

- When major tank rupture occurs, none of the proposed systems would significantly reduce the fire hazard to passengers and equipment.
- Inerting, quenching, and suppression systems incur tremendous economic and operational penalties for the small benefits offered.
- Systems currently used in commercial aircraft provide protection equivalent to inerting, quenching, or suppression systems when the tanks remain intact.

AD-A099 147 FEDERAL AVIATION ADMINISTRATION WASHINGTON DC OFFICE--ETC F/G 1/2
SPECIAL AVIATION FIRE AND EXPLOSION REDUCTION (SAFER) ADVISORY --ETC(U)
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TANK EXPLOSION ACCIDENT RATE
WORLD WIDE AIR CARRIERS - ALL OPERATORS

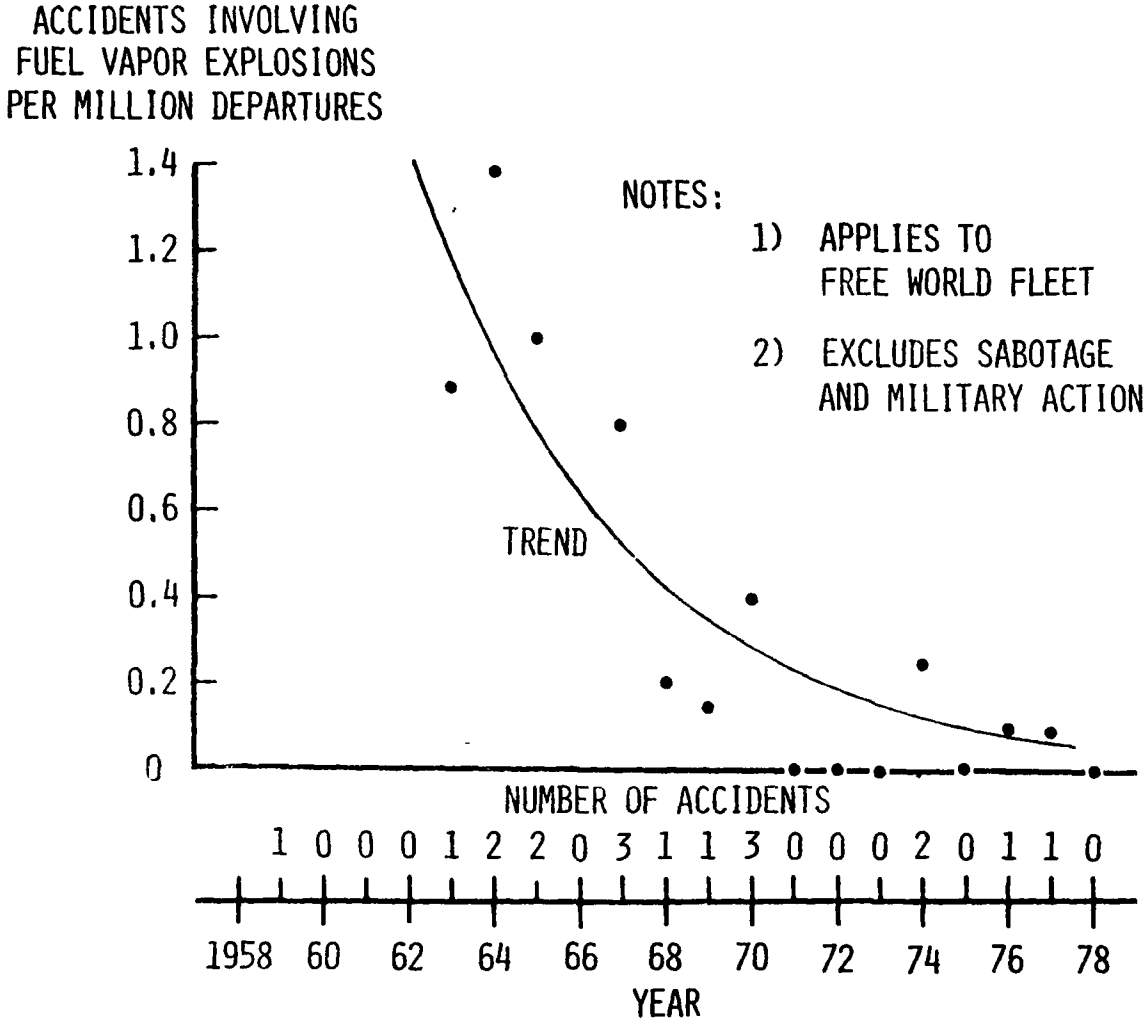


Figure 3

IV. Crash-Resistant Fuel Tanks (Reference 2)

The term "crash-resistant" fuel tank is generally associated with fuel tanks that are capable of remaining reasonably intact during a crash event, thereby eliminating or minimizing fuel spillage and the corresponding post-crash fire threat to surviving passengers. If achieved, this concept can eliminate most destructive external fires and complement the simple measures discussed in the previous section. The highly visible success of crash-resistant fuel systems installed in Army helicopters makes direct application of this technology to jet transport aircraft tempting. However, the obvious differences in aircraft characteristics, crash scenarios, and accident experience may dictate another course of action.

The obvious difference in fuel system and aircraft design and the crash scenario is further complicated by the definition of "impact survivable." The Army bases its determination of whether or not an accident is impact survivable on an assessment of the inertia forces transmitted to the occupant through his seat and restraint system and on whether or not the cabin structure collapsed within the occupant's envelope. On the other hand, the FAA considers a crash survivable if one occupant survives the impact event. Because of the size of transport aircraft and the correspondingly high energy absorbing potential, it is conceivable that some occupants will survive very high crash impact velocities. On the other hand, because of the fairly small size of Army helicopters, all occupants and systems are exposed to approximately the same crash environment facilitating a relatively clean definition of an impact survivable crash.

The transport fuel tanks fall broadly into two categories - integral wing tank and fuselage tank. The application of crashworthy bladder tanks to integral wing tanks cannot be accomplished without a complete redesign of the wing because of its multi-cellular construction. Furthermore, it cannot be said with certainty that crash-resistant fuel tanks would provide fire protection in crash scenarios that include wing separation.

Before discussing the application of crash-resistant fuel tanks in the fuselage area, something should be said about current fuselage design practices.

Current commercial aircraft typically carry fuel in the wings and in some cases the fuselage. Fuselage fuel may be carried in the center wing structure or in a pressurized area such as a cargo compartment. Fuel tanks in the center wing structure are designed to meet the "g" loads prescribed for emergency landings (Figure 4).

Federal regulations require that damage to the airplane main landing gear system during takeoff and landing shall not cause spillage of enough fuel to constitute a fire hazard. The fuel tank and landing gear support structure is designed to a higher strength than the gear to prevent fuel tank rupture due to an accidental landing gear overload. This design requirement is further extended to include structural attachments to the wing fuel tank which might be overloaded during a wheels-up or partial wheels-up landing. Flap hinges and engine mounts for example are designed to fail without rupturing the tank.

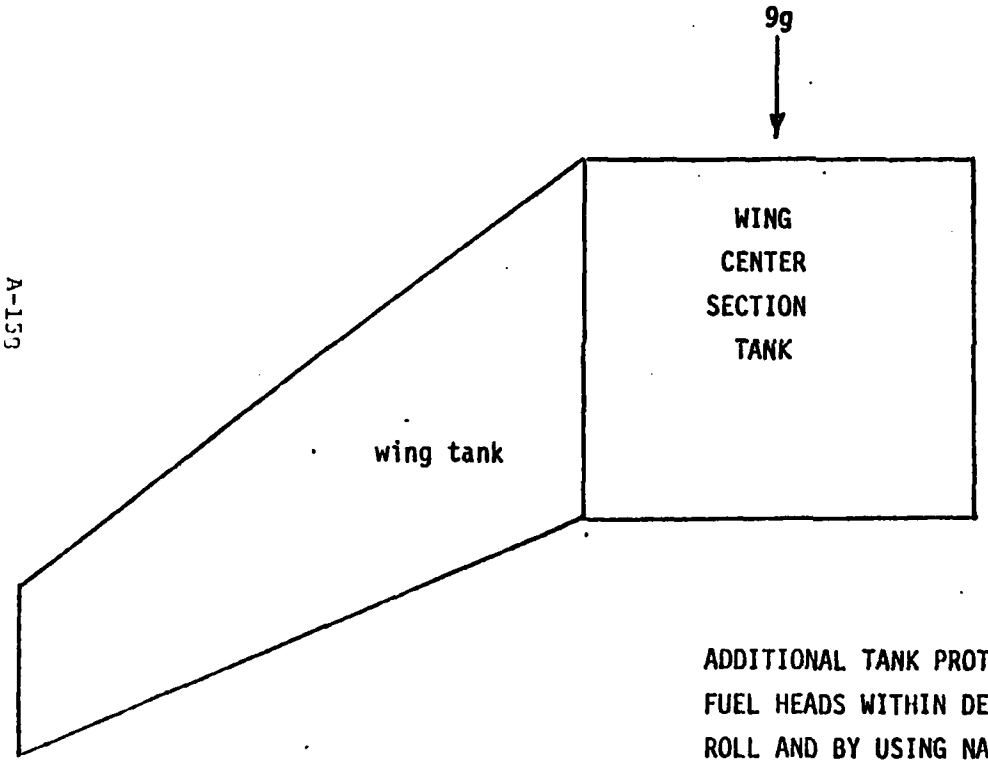
In airplanes having fuel tanks located within the pressurized area, typically the cargo compartment, particular attention is paid to minimize the risk of fuel spillage. An example of one such design is shown on Figure 5. The tank is composed of an aluminum honeycomb outer shell with bladder cells inside. The tank is supported from the floor beams in such a manner as to preclude body structure deflections from loading the tank. Clearances from adjacent structure are provided around the tank.

The fuel and vent lines that connect the tanks to the main fuel system incorporate drainable and vented shrouds. These lines are either designed to "break away" from the auxiliary tank or sufficient stretch is provided to accommodate tank movement without causing fuel spillage. Hoses that are required to stretch are subjected to what is normally referred to as the guillotine test. The hose is pressurized and clamped at both ends to simulate

FUEL TANK LOAD FACTORS

WING CENTER SECTION
DESIGNED PER FAR 25.561

FORWARD	9.0g
DOWNWARD	4.5g
UPWARD	2.0g
SIDEWARD	1.5g



ADDITIONAL TANK PROTECTION OBTAINED BY KEEPING FUEL HEADS WITHIN DESIGN LIMITS DURING 1 RADIAN/SEC. ROLL AND BY USING NACELLE STRUT, LANDING GEAR AND TRAILING EDGE FLAPS ATTACHMENTS FOR CONTROLLED BREAKAWAY.

Figure 4

CARGO COMPARTMENT TANK INSTALLATION

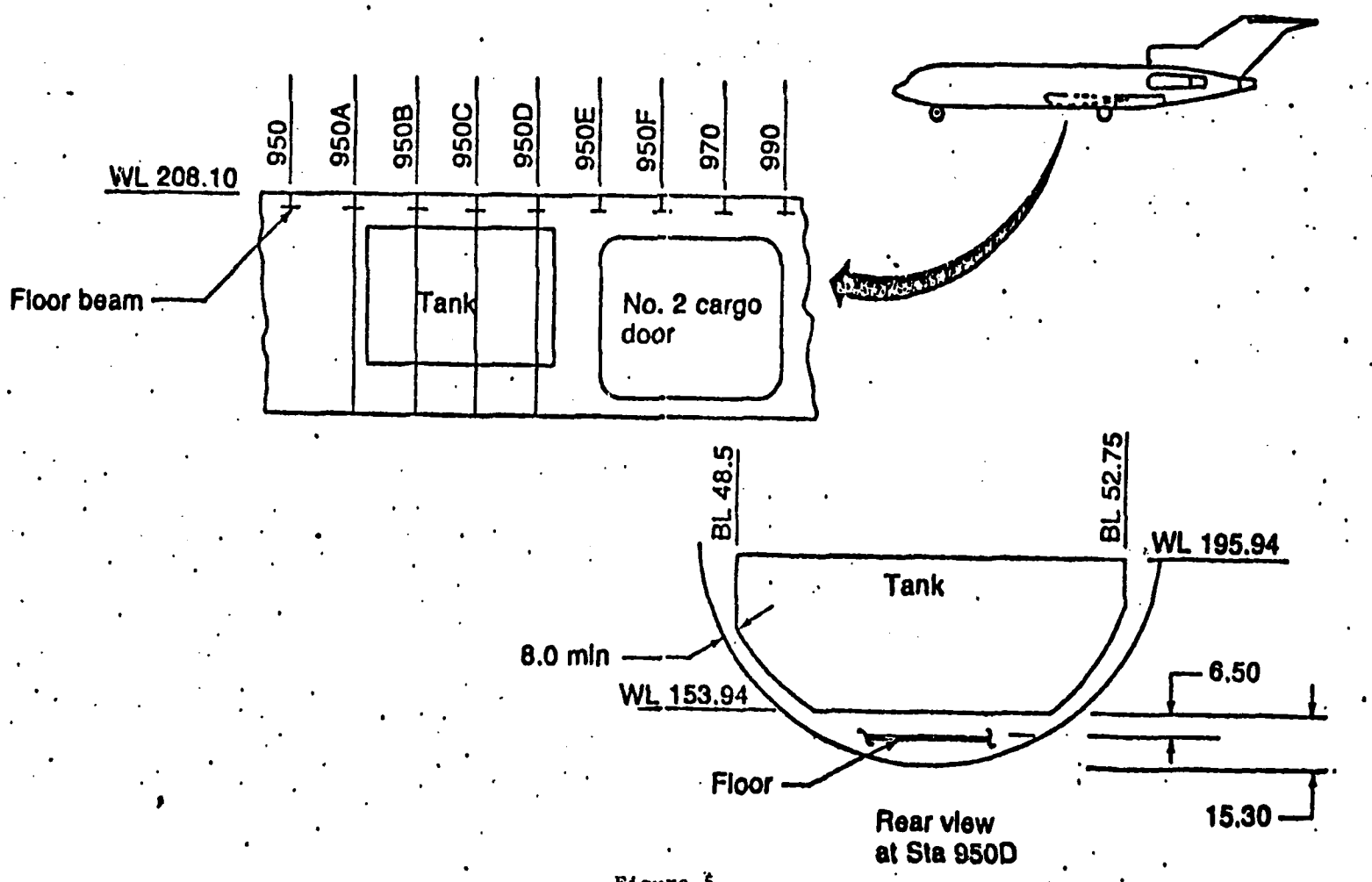


Figure 5

it's mounting in the aircraft, then a sharp pointed load is applied in the middle of the hose. The hose must not leak when stretched to it's maximum.

In addition prior accident history is reviewed to ensure that the tank installation will minimize the possible leakage of fuel. For example accidents or incidents where the gear has separated are reviewed to insure that the tank will not be hit by a displaced gear. Also incidents or accidents where the body has been crushed are reviewed to insure that there is adequate clearance between the body and the fuel tank. In addition incidents or accidents where the body has broken are reviewed to ensure that the auxiliary tank is not located where such breaks typically occur.

In summary, it can be said that the body fuel tank design:

- o Exceeds FAR requirements.
- o Is more rugged than center section tanks.
- o Considerable clearance is maintained.
- o Fuel lines allow tank displacement without breakage.
- o Accident history indicate minimal spillage exposure.

Without test verification it cannot be said that crash-resistant tanks installed in the transport aircraft fuselage tanks would be completely effective. Although it might not be the optimum configuration, it would certainly be a significant improvement over the current bladder tanks since this improvement would be realized adjacent to the occupants where crash fire protection is urgently needed.

To this end, an evaluation of crash-resistant fuel tank installations in wing and fuselage areas was performed. A summary of the results of this evaluation is shown in Figure 6. As anticipated, the wing installation shows excessively high penalties in almost every category evaluated. On the other hand, the fuselage installation resulted in only low to moderate penalties.

The results of this brief evaluation indicate that a careful analysis of crash data history to explore modes of failure is essential to determine if improvement of fuel retention during transport airport crashes can be achieved. A research program involving the 3 domestic widebody airframe manufacturers is anticipated to be initiated near the end of 1979 for the purpose of developing crash scenarios and recommending future test and analysis effort for the development of improved crashworthiness.

As a result of this study, the group arrived at the following conclusions:

- It is feasible to install crash-resistant fuel cells in fuselage cargo compartments.
- It is not feasible to install crash-resistant fuel cells in the wings of conventional transport aircraft.
- Existing Federal Aviation Regulations are adequate.
- Further definition of criteria should evolve from total aircraft crashworthiness considerations.

CRASH-RESISTANT FUEL TANKS

SUMMARY EVALUATION OF CONCEPTS

CONCEPT	WEIGHT	VOLUME	COST	RELIABILITY	RETROFIT CAPABILITY	EFFECTIVENESS
CRT IN FUSELAGE	MODERATE	LOW	LOW	PASSIVE	FEASIBLE	NOT VS. ALL POSSIBILITIES
CRT IN WING	HIGH	HIGH	HIGH	PASSIVE	DIFFICULT	NOT VS. ALL POSSIBILITIES
LEADING EDGE REINFORCEMENT	MODERATE	LOW	LOW	PASSIVE	REDESIGN	UNKNOWN
BREAKAWAY FITTINGS	LOW	NONE	MODERATE	TEST REQUIRED	REDESIGN	NOT PROVEN
DOUBLE WALLS AT SEPARATION POINTS	MODERATE	LOW	MODERATE	TEST REQUIRED	NOT FEASIBLE	FOR WING SEPARATION
35g DESIGN INTEGRAL TANKS	HIGH	MODERATE	HIGH	TEST REQUIRED	DIFFICULT REDESIGN	NOT FOR PENETRATION
INTERNAL LINERS	HIGH	LOW	LOW	MUST ENSURE RETENTION	FUEL COMPATIBILITY REQUIRED	LIMITED

Figure 6

V. Anti-Misting Fuels (Reference 3).

Anti-misting kerosene (AMK) has reached the current level of development as the latest in the search for a "crash safe" aircraft turbine fuel. The fundamental consideration in crash safe fuel development has been to produce a fuel which will not result in the fine fuel mists which will propagate a flame from an ignition source to a larger supply of fuel in a rapid manner. These mists are generated by the high shear rate expulsion of fuel from a small tank opening or by air shear/breakup of larger masses of fuel expelled during deceleration. Preventing the rapid development of a large fire around an aircraft involved in an impact survivable accident where fuel tank rupture occurs can allow more time for passenger and crew evacuation and result in a higher rate of survivability in this type accident.

The anti-misting quality is imparted to the fuel by the addition of low concentrations of shear-sensitive hydrocarbon polymers. The additive currently being evaluated by the FAA is know as FM-9. It has been shown to be effective in reducing flame propagation through mists of kerosene fuels of contemporary flash point levels (100°F and above). Tests using anti-misting additive in wide-cut fuels of low flash point (near 0°F) and high volatility (e.g. JP-4, Jet B) show little relative effectiveness in similar tests.

AMK is in the early stages of its development. Although it has already demonstrated its ability to minimize, and in most cases eliminate entirely, the fireball frequently experienced when fuel is released during a crash, many factors are yet to be investigated. At the present time the FAA and the United Kingdom have a joint program which will culminate near the end of 1980 in a decision to continue further development of AMK as a concept or to discard it as not being feasible for commercial aircraft application.

Major questions yet to be answered include the effects of the additive on static charge generation and relaxation, engine starting and relight

characteristics, heat transfer characteristics, filterability, materials compatibility, fuel oxidative stability and storage stability. The most important property of AMK, its tendency to form large droplets when released, is not a desirable characteristic when the fuel reaches the engine combustor. Consequently, development of a degrader which takes advantage of the thixotropic nature of AMK to restore its ignitability just prior to entering the engine combustor, is high on the list of development priorities.

Although no specification for AMK exists as yet, the following properties have been established as targets:

- An additive concentration of approximately 0.3 percent.
- Heat content equivalent to Jet A/A-1.
- Anti-misting quality maintained during handling.
- Minimum impact on engine start and relight.
- Acceptable pumpability and flowability.
- Compatible with existing materials and components.

In spite of the many questions yet to be answered, the reaction to AMK is favorable at this stage of its development. Its fluidity has been improved significantly without compromising its anti-misting qualities. The development of a suitable degradation process is encouraging. Test programs are continuing in the areas of engine and fuel systems compatibility, air shear and flammability, and rheology definition. In addition, large scale crash tests are being implemented. If no unacceptable aspects of AMK develop in the continuing program, it is estimated that it could be introduced for commercial aircraft usage in approximately 10 years.

In conclusion, it can be said that AMR offers a tremendous potential for post-crash fire hazard reductions. It should have a minimum impact on aircraft operation and maintenance. Although it appears to be the most promising candidate to reduce the fire hazard in a post-crash environment, much more development effort will be required before this potential can be realized.

VI. Recommendations - Near Term

The results of the group studies do not offer much encouragement for immediate rule making consideration. Existing FAR's were reviewed to determine if they should be revised to conform to existing technology. This review uncovered two areas in which some revision could be considered:

- Fuel vent protection during ground fires.

- Assurance of emergency fuel shutoff prior to a crash.

However, neither of these changes would affect the safety of current commercial jet transports inasmuch as most of them already incorporate these features.

VII. Recommendations - Research and Development

Progress towards safer airplanes will only come through directed research and development efforts. As a result of this study, it is recommended that:

- The FAA actively support the Air Force on-board nitrogen generator investigations.

- The FAA investigate the effectiveness of the fuel tank self-inerting concept discovered in NAFEC under wing fire tests.

- The FAA await the results of the anticipated NASA/FAA crashworthiness studies and support a study defining crashworthiness design criteria if indicated.

- The FAA extend the AMK investigations.

Industry and government representatives are continually analyzing the results of crash investigations to determine better ways to protect aircraft against the consequences of crashes including post-crash fires. However, investigators are continually hampered by the fact that inadequate data is recorded in crash reports. This fact prompts the inclusion of one further recommendation:

- The FAA should support the Coordinating Research Council recommendations for improved accident reporting.

VIII. References

1. Report of the Sub-Group on Explosion Suppression, Fuel Tank Foam/Foil, and Fuel Tank Inerting.

2. Report of the Sub-Group on Crash-Resistant Fuel Tanks.

3. Report of the Sub-Group on Anti-Misting Fuels.

IX. Appendix A

Revised: July 30, 1979

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X. Appendix B

MEMBERSHIP OF SUB-GROUPS ON POST-CRASH FIRE HAZARD REDUCTION

I. Explosion Suppression, Fuel Tank Foam/Foil and Fuel Tank Inerting.

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Don L. Davis - United Air Lines

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Don Crosby - Eastern Airlines

Bruce Honsberger - Boeing Commercial Airplane Company

Charles Pedriani - Army Research and Technology Labs

Alec Binding - McDonnell Douglas Corporation

III. Anti-Misting Fuels

A. Thomas Peacock, Chairman - McDonnell Douglas Corporation

Mike Trimble - Delta

W. G. Dukek - Exxon Research and Manufacturing

R. J. Mannheimer - Southwest Research Institute

EXPLOSION SUPPRESSION,

FUEL TANK FOAM FOILS

AND FUEL TANK INERTING

PRESENTATION TO SAFER TECHNICAL GROUP

BY H. SKAVDAHL

9-25-79

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SUB-GROUP OBJECTIVES

- EVALUATE NEED OF CANDIDATE SUPPRESSION/INERTING SYSTEMS
- DETERMINE THE NEED FOR SHORT TERM RULE MAKING
- DETERMINE IF APPROPRIATE R&D IS BEING ACCOMPLISHED
- SUBMIT REPORT TO SAFER TECHNICAL GROUP ON FINDINGS

FIGURE 1. TANK EXPLOSION ACCIDENT RATE WORLD WIDE AIR CARRIERS - ALL OPERATORS

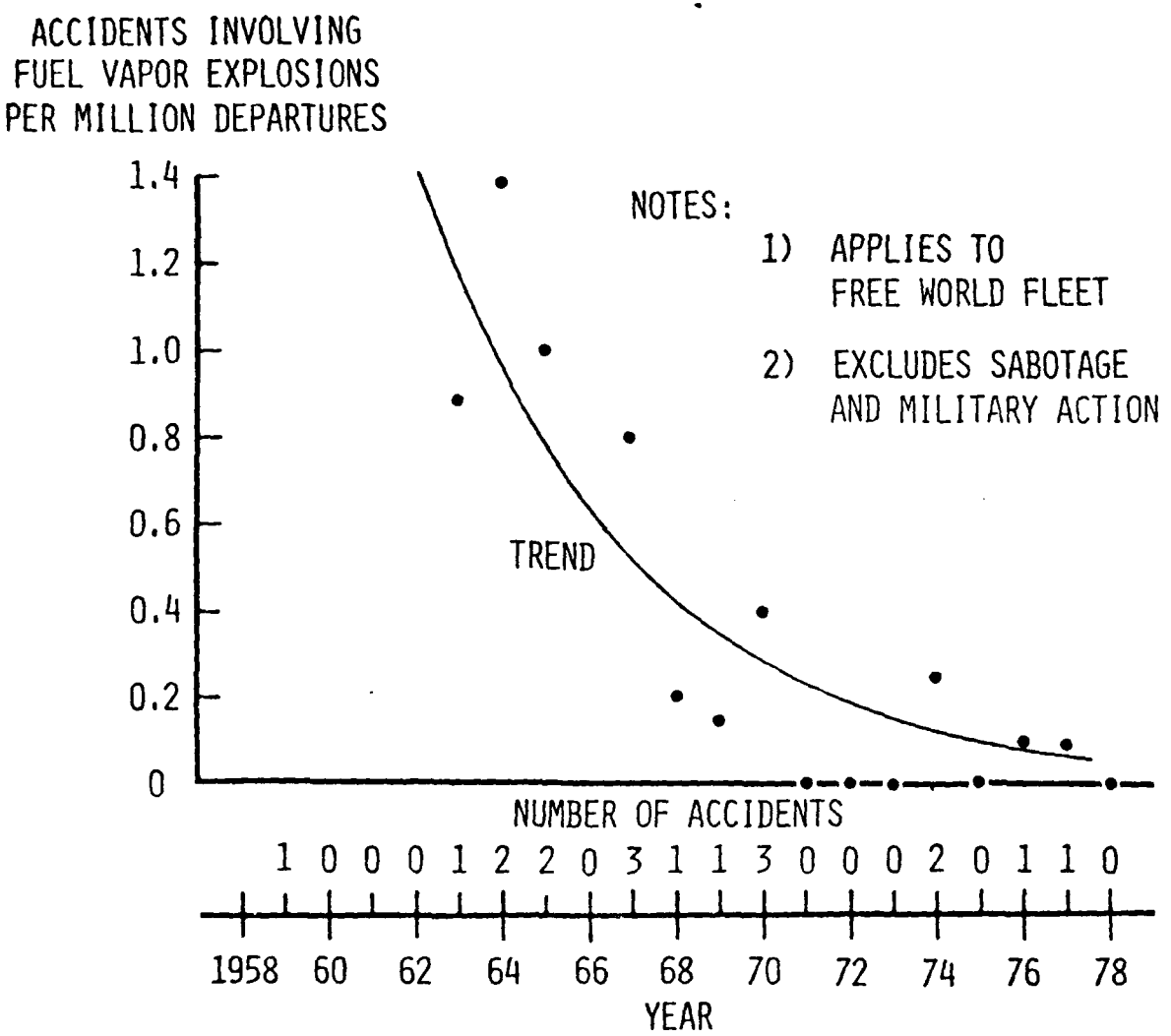


FIGURE 2. TANK EXPLOSION ACCIDENT ASSESSMENT (POST CRASH FIRES)

(WORLD-WIDE TURBOJET FLEET)

	MODEL	YEAR	FATALITIES	SURVIVORS	HULL LOSS	FUEL	JP-4	POTENTIAL REDUCED FATALITIES OR HULL DAMAGE: VENT ARRESTER OR SUPPRESSOR	POTENTIAL REDUCED FATALITIES OR HULL DAMAGE: IMPROVED FUEL CUTOFF	POTENTIAL REDUCED FATALITIES OR HULL DAMAGE: TANK INERTING	LOW PROBABILITY OF ANY SYSTEM BENEFIT
GROUND FIRE-MINOR IMPACT DAMAGE	ROME	707	1964	48	25	Y	JP-4	X		X	
	LONDON	707	1968	5	121	Y	KERO.		X	X	
	SINGAPORE	CMT	1964	0	68	Y	?	X			
	STOCKTON	DC-8	1969	0	4	Y	?		X	X	
MASSIVE GROUND FIRE -WING TANK BREAKUP -SEVERE BODY DAMAGE	ANCHORAGE	DC-8	1970	47	182	Y	KERO.				X
	MONROVIA	DC-8	1967	51	39	Y	?				X
	CINCINNATI	880	1965	70	12	Y	KERO.				X
	CINCINNATI	727	1967	58	4	Y	KERO.				X
	ST. THOMAS	727	1970	2	51	Y	KERO.				X
	PAGO PAGO	707	1974	97	4	Y	KERO.				X
	NAIROBI	747	1974	59	97	Y	KERO.				X
	TENERIFE	747	1977	335	61	Y	KERO.				X
	NEW HOPE	DC-9	1977	62	23	Y	KERO.				X

FAA ANALYSIS OF ACCIDENTS INVOLVING FUEL TANK EXPLOSIONS

PERIOD: 1964 - 1974

- FIVE ACCIDENTS ACCOUNTED FOR 131 FATALITIES

  IN WHICH SUPPRESSION/INERTING COULD HAVE REDUCED CASUALTIES

- CURRENT DESIGN PRACTICE WOULD HAVE PREVENTED EXPLOSIONS

  IN TWO CASES (ROME AND LONDON) (53 FATALITIES)

- OTHER THREE CASES: DEBATABLE

  (ANCHORAGE AND TWO TURBO-PROP ACCIDENTS)

FUNCTION OF FUEL TANK SUPPRESSION/INERTING

- PREVENTS EXFLOSIONS IN UNDAMAGED FUEL TANKS
- DOES NOT REDUCE EXTERNAL FIRE FROM RUPTURED TANKS
- THEREFORE, APPLICATION TO POST CRASH FIRE HAZARD IS LIMITED

CANDIDATE SYSTEMS EVALUATED

- EXPLOSION SUPPRESSION
- PLASTIC FOAM
- METALLIC FOIL
- INERTING
  - LN_2
  - GN_2 (ONBOARD N_2 GENERATION)

EXPLOSION SUPPRESSION SYSTEM

- EXTREMELY COMPLEX SYSTEM:
  - MANY SENSORS
  - DISCHARGE BOTTLES
  - DISTRIBUTION PLUMBING
- SYSTEM MAINTENANCE DIFFICULT
- INADVERTENT FIRING LIKELY
- PREVIOUS STUDIES NOT FAVORABLE
- CONCLUSION: SYSTEM NOT PRACTICAL FOR COMMERCIAL APPLICATION

PLASTIC FOAM

- PERFORMANCE PENALTIES:
  - WEIGHT OF FOAM
  - WEIGHT OF FUEL RETAINED

    } 14,000 LB FOR 747 (40% VOIDED)
  - LOSS OF FUEL VOLUME (0.75 TO 2.0%)
- MAINTENANCE:
  - STRUCTURAL INSPECTION DIFFICULT
  - INSPECTION & REPAIR OF FUEL SYSTEM COMPONENTS DIFFICULT
  - MICROBACTERIAL GROWTH ENHANCED
- EFFECTIVITY IN EXTERNAL FIRE UNKNOWN
  - (MELTING POINT ~ 360°F)
- CONCLUSION:
  - FOAM NOT PRACTICAL FOR COMMERCIAL APPLICATION

METALLIC FOIL

PREVIOUS DISCUSSION ON FOAM APPLIES.

EXCEPT:

- INSTALLATION MORE DIFFICULT
  - FOIL IS SEMI-RIGID
  - NO MEMORY
- AIRCRAFT MAINTENANCE MORE DIFFICULT
- EFFECTIVITY IN EXTERNAL FIRE IS EXCELLENT
  - (MELTING POINT - 1100°F)

CONCLUSIONS:

- FOIL NOT PRACTICAL FOR COMMERCIAL APPLICATION
- IT MAY BE USEFUL IN TANKS OF EMERGENCY VEHICLES

TABLE 1. ENGINE DISINTEGRATION FUEL TANK PENETRATION OCCURRENCES

DATE	A/C TYPE	LOCATION	FLIGHT PHASE	ACCID/INCID
11-4-61	720B	NR. ALBANY	CRUISE 27,000 FT	ACCID.
6-28-65	707-321B	SAN FRANCISCO	INIT. CLIMB 800 FT	ACCID.
11-18-65	880	LOS ANGELES	INIT. CLIMB	INCID.
5-17-66	720B	KANSAS CITY	TAKEOFF	INCID.
9-9-67	707-321	FRANKFURT	TAKEOFF	ACCID.
11-3-67	DC-8-40	CHICAGO	INIT. CLIMB	ACCID.
11-21-67	707-465	HONOLULU	TAKEOFF	ACCID.
6-4-68	707-321C	HONOLULU	CLIMB	ACCID.
11-18-68	707-323C	DULLES	CLIMB	ACCID.
11-28-69	DC-8	NEWARK	TAKEOFF	INCID.
4-19-70	DC-8-62	ROME	TAKEOFF	ACCID.
9-18-70	747	SAN FANCISCO	TAKEOFF	INCID.
7-21-71	707-323C	DALLAS	TAKEOFF	INCID.
1-20-73	707-320B	CHICAGO	CLIMB 1300 FT	ACCID.
11-3-73	DC-10	ALBUQUERQUE	CRUISE 39,000 FT	ACCID.
2-15-75	707-338C	HONG KONG	CRUISE 32,000 FT	INCID.
9-23-75	707	UNKNOWN	TAKEOFF	INCID.
11-25-76	707	MEDINA	INIT. CLIMB	INCID.
9-14-77	DC-10	JOANNESBURG	TAKEOFF	INCID.
4-6-78	707	SINGAPORE	TAKEOFF	INCID.
1-6-79	707	VIENNA	CLIMB	INCID.

LIQUID NITROGEN INERTING SYSTEM

BACKGROUND EXPERIENCE:

OPERATIONAL ON C-5A AIRPLANE

AIR FORCE CREDITS THE SYSTEM WITH PREVENTION OF TWO IN-FLIGHT FIRES FROM BECOMING CATASTROPHIC

1. ELECTRICAL SHORT CAUSED HYDRAULIC FLUID FIRE
2. TURBINE BLADES PENETRATED FUEL TANKS

APPLICATION OF ABOVE EXPERIENCE TO COMMERCIAL ENVIRONMENT

- HYDRAULIC FLUID IS FIRE RESISTANT
- NUMEROUS CASES OF WING EXPOSURE TO EXTERNAL FIRE WITHOUT CAUSING EXPLOSION
- OF TWENTY-ONE CASES OF FUEL TANK PENETRATION BY ENGINE DEBRIS NONE HAVE CAUSED TANK EXPLOSION (146 MILLION FLIGHT HOURS)

LIQUID NITROGEN INERTING SYSTEM (CONTINUED)

UPDATE OF LN_2 COSTS FOR B-747 AIRPLANE

	1976 ESTIMATE (DUAL REDUNDANT SYSTEM)	CURRENT ESTIMATE (SINGLE SYSTEM)
COST/FLIGHT HOUR (DOLLARS)		
PRODUCTION	34.02	43.18
RETROFIT	50.74	51.82
COST/AIRPLANE/YEAR (DOLLARS)		
PRODUCTION	105,462	133,858
RETROFIT	157,294	160,642

LIQUID NITROGEN INERTING SYSTEM (CONTINUED)

20-YEAR COSTS FOR TOTAL FLEET

A/P TYPE	1976 ESTIMATE (10^6 DOLLARS)	1979 ESTIMATE (10^6 DOLLARS)
4 EWB	3,361	5,111
2 ESB	3,533	5,446
3 ESB	1,911	3,744
4 ESB	832	940
2/3 EWB	6,890	8,598
TOTAL	16,527	23,839

LIQUID NITROGEN INERTING SYSTEM (CONTINUED)

CONCLUSION:

THE COST OF THE SYSTEM

DOES NOT JUSTIFY ITS APPLICATION

FOR THE SMALL POTENTIAL BENEFIT.

ONBOARD NITROGEN GENERATION (GN2) SYSTEM

- ADVANTAGES OVER LN_2 SYSTEM:
  - LOGISTICS SYSTEM NOT REQUIRED FOR LN_2
  - POTENTIALLY LIGHTER WEIGHT
  - LOWER PERFORMANCE PENALTY AND COST
- CURRENT STATUS:
  - RESEARCH AND DEVELOPMENT PHASE
  - AIR FORCE SPONSORING R&D
- CONCLUSION:
  - GN_2 SYSTEM HAS SOME POTENTIAL FOR COMMERCIAL APPLICATION.
  - R&D SHOULD BE CONTINUED.

CONCLUSION SUMMARY

- DEFINITIVE EVALUATION OF BENEFITS FOR TANK EXPLOSION SUPPRESSION/INERTING SYSTEM NOT POSSIBLE
- CANDIDATE SYSTEMS NOT FINANCIALLY JUSTIFIED
- CANDIDATE SYSTEMS IMPOSE UNACCEPTABLE OPERATIONAL IMPACT ON AIRLINES
- SAFETY FEATURES IN CURRENT USE PROVIDE MAJORITY OF BENEFIT EXPECTED FROM SUPPRESSION/INERTING SYSTEMS

REVIEW OF CURRENT FAR'S

- RULES RELATED TO CRASH WORTHINESS CONSIDERED ADEQUATE
- TWO AREAS FOR POTENTIAL IMPROVEMENT
  - FUEL VENT PROTECTION FROM GROUND FIRE
  - ASSURED EMERGENCY FUEL SHUTOFF

RECOMMENDATIONS

- SHORT TERM RULE MAKING
  - FUEL VENT PROTECTION FROM GROUND FIRE
  - ASSURED EMERGENCY FUEL SHUTOFF
- RESEARCH & DEVELOPMENT
  - CONTINUE R&D OF ONBOARD N_2 GENERATION SYSTEM
  - INVESTIGATE SELF-INERTING PHENOMENON AND METHODS OF ENHANCEMENT
- EMERGENCY GROUND VEHICLES
  - INVESTIGATE APPLICATION OF METALLIC FOIL TO EMERGENCY GROUND VEHICLES

CRASH-RESISTANT FUEL CELLS

SAFER ADVISORY COMMITTEE

Sub-Group Report

September 1979

Sub-Group Members:

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SUMMARY

This report presents the findings of the Post Crash Fire Hazard Reduction (PCFHR) subgroup on crash-resistant fuel cells. Helicopter experience with pre- and post-crashworthy fuel systems along with approximate weight and cost associated with crash-resistant fuel systems are presented. The current status of crash-resistant fuel cells for transport aircraft is described along with typical illustrative design and construction. Various fuel crash-resistant and containment concepts are evaluated in a matrix which takes into consideration weight, volume, range, cost, maintainability, reliability, hazards, retrofit effectiveness, equivalent protection and general commentary.

A discussion of the results of a limited number of transport aircraft NTSB accident records and a brief description of an anticipated transport aircraft crashworthiness research effort involving the thorough evaluation of accident data and the development of crash scenarios is provided. Conclusions and Recommendations based on the findings of the subgroup are presented.

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GLOSSARY OF TERMS

Crash Resistant - capability to resist specified loads

Crashworthy - meets FAA requirements

Fuel Tank - any cavity containing fuel

Fuel Cell - compartment within a fuel tank

Fuel Bladder - fuel resistant rubber material shaped to fit a cavity

Fuel Containment - the ability to hold fuel in a crash environment within the limits of a fuel cell, bladder or tank

Fuel Curtain - non-load carrying device to prevent passage of vapor fumes

Integral Tank - tank in which fuel is contained within the structure and no rubber bladder is provided.

SECTION 1

INTRODUCTION

PURPOSE

In June of 1978 the establishment of the Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee was authorized. The objective of this committee is to increase the safety of passengers in a survivable crash environment for transport category aircraft. Two technical groups covering the areas of Post-Crash Fire Hazard Reduction and Interior Materials Fires were formed to report to the SAFER committee. As part of the Post-Crash Fire Hazard Reduction technical group the following three subgroups were created:

- Fuel Inerting, Foam/Foil Explosion Suppression
- Antimisting Fuels
- Crash-resistant Fuel Cells

This report contains the finding of the Crash-Resistant Fuel Cells subgroup.

OBJECTIVES

The assigned project objectives for the subgroup on Crash-Resistant Fuel Cells are:

- Determine the current status of crash-resistant fuel tanks,
- Evaluate how crash-resistant fuel tanks would be designed into the transport airplane structure, and
- Define what needs to be done before crash-resistant fuel cells can/will be integrated into the production of transport category airplanes.

FUNCTION IN A CRASH ENVIRONMENT

The term "crash-resistant fuel tank" is generally associated with fuel tanks that are capable of remaining reasonably intact during a crash event, thereby eliminating or minimizing fuel spillage and the corresponding post crash fire threat. For aircraft application, crash-resistant fuel tanks are designed to contain the fuel during crash scenarios up to the limit of those considered impact survivable, thereby ensuring that if occupants survive the impact event there will be no post-crash fire to impede their evacuation.

Good design practice would indicate that an engineering definition of the upper limit survivable crash should be developed and the crash-resistant fuel system be designed to tolerate that level. The method of achieving the crash resistance should then be determined based on aircraft design and anticipated crash scenarios.

For most situations fuel containment is highly desirable because it directly controls the main source of fire hazard. If achieved, it eliminates post-crash fire negating the need for other protection measures such as explosion suppression, thermal barriers, etc. In severe crash scenarios, however, it may be prudent to supplement the containment approach with other measures at potential weak points or abandon it altogether in favor of other crash-resistant approaches.

The helicopter crashworthy fuel system achieves containment through high-strength bladder tanks that can tolerate large strains and resist tearing from localized impacts, and through self-sealing breakaway valves.

It should be mentioned that complete containment may not be necessary to eliminate burn injuries and fatalities. If the fuel system can eliminate massive fuel release and confine the leakage to minor, scattered spills so that only slow-progressing fires are possible, a great improvement will be realized.

HELICOPTER BACKGROUND

Accident studies done about 10 years ago (summarized in Table 1-1) of Army helicopters not equipped with crashworthiness features clearly

TABLE 1-1. NUMBER OF PEOPLE KILLED IN U.S. ARMY HELICOPTER ACCIDENTS BY INADEQUATE CRASHWORTHY FEATURES.

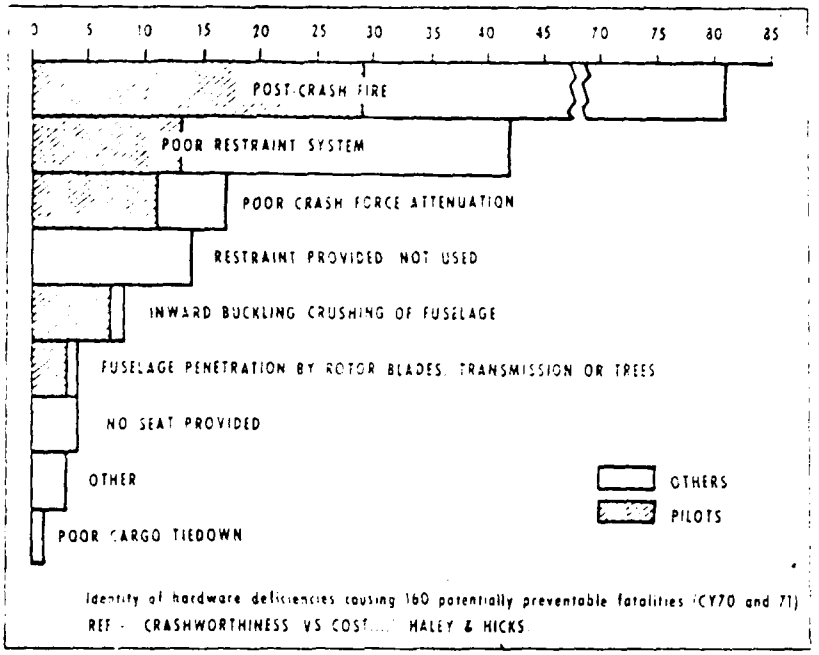


TABLE 1-2. COMPARISON OF POSTCRASH FIRE EXPERIENCE

	WITHOUT CWFS	WITH CWFS
TOTAL MISHAPS	1089	1083
POSTCRASH FIRES	84	25

CASUALTIES BY TYPE OF FUEL SYSTEM

	WITHOUT CWFS	WITH CWFS
THERMAL FATALITIES	65	0
INJURIES	23	1
NON THERMAL FATALITIES	340	98
INJURIES	525	340

REFERENCE - USAAAVS SYSTEM SAFETY NEWSLETTER, VOL 4, #4, 1975

indicated that lives were being lost unnecessarily, and provided the impetus for major development and incorporation of crashworthy features into Army helicopters. Emphasis was placed on the overall integration of many crashworthy features into the aircraft through improvements in basic design. Design criteria for improved crashworthiness were generated and are outlined in "Crash Survival Design Guide," USAAMRDL TR 71-22 (Reference 1). Because of the large number of fatalities attributed to post-crash fire, a major portion of this effort involved the development of the crashworthy fuel system (CWFS). A retrofit program was initiated in 1970 to equip all Army helicopters with the CWFS. The accident statistics compiled between 1971 and 1975 when both non-crashworthy and crashworthy fuel systems were in the active Army inventory document the performance of the CWFS, (Table 1-2). The highly visible success of the CWFS makes direct application of this technology to jet transport aircraft tempting. The obvious differences in aircraft characteristics, crash scenario, and accident experience may dictate another course of action, however. Although accident experience analysis can be misleading, it appears that the helicopter accident experience clearly justified emphasis on development of a crashworthy fuel system, whereas the jet transport accident experience may not justify the expenditure of available resources on crash-resistant fuel systems in lieu of other life saving measures.

The heart of the CWFS is the crashworthy tank. It is the result of a material development program where the crash environment was analyzed and specifications identified which were necessary for a material to retain fuel during the crash event. The material had to tolerate large strains and be resistant to tearing and cutting from damaged structure and foreign objects. The test criteria specified in MIL-T-27422B (Reference 2) are used to select tank materials to survive the helicopter crash environment. These tests include measurements of tear and puncture resistance, environmental stability and long-term leakage. Most materials developed to date which satisfy this specification are nylon fabric/rubber laminates which also contain specialized sealing provision for combat threats. It is equally important that the basic tank material be fabricated into a complete tank which is crash resistant. This fabrication normally involves cut-and-try layup, which may vary in thickness

TABLE I-1. APPROXIMATE WEIGHT AND COST TO RETROFIT CRASH-ATTENUATING AND BALLISTIC-RESISTANT FUEL SYSTEMS INTO ARMY AIRCRAFT

AIRCRAFT	INCREASE IN EMPTY WEIGHT (lbs)	DECREASE IN USEABLE FUEL (Gal	DEVELOPMENT COST	INSTALLATION COST HARDWARE	M-hrs
AH-1	130	6	$250,000	$4600	400
CH-47C	610	54	$2,215,000	$20000	700
OH-58	67	1.5	$320,000	$4200	80
UH-1H	160	11	$362,000	$7400	320

REF. — USAAAVS, 1975

[illegible] is impact survivable [illegible] assessment [illegible] transmitted to the occupant [illegible] and restraint system, [illegible] not the cabin structure. [illegible] from the [illegible] however, [illegible] considers [illegible] Because of the size [illegible] and the [illegible] absorbing potential, [illegible] very high impact velocities. [illegible] small size of Army helicopters, [illegible] the same fuel containment [illegible] impact velocities [illegible]

[illegible]

[illegible]

TABLE 1-4. 95th PERCENTILE SURVIVABLE HELICOPTER ACCIDENT PULSE

DIRECTION ALONG AIRCRAFT AXIS	VELOCITY CHANGE FT/SEC
Vertical (downward)	42
Lateral	30
Longitudinal (forward)	50
Resultant Vector*	50

*NOTE: The downward, sideward, and forward velocity components of the resultant velocity vector do not exceed 42, 30, and 50 ft/sec respectively.

tanks, it may also be suitable or beneficial for transport fuselage tanks. It seems, however, that the application of crashworthy bladder tanks to integral wing tanks could not be accomplished without a complete redesign of the wing itself. Furthermore, it cannot be said with certainty that the helicopter CWFS would provide fire protection in crash scenarios that include wing separation. Without test verification it cannot be said that the CWFS installed in the transport aircraft fuselage tanks would be completely effective.

SECTION 2

DISCUSSION OF CONCEPTS - CURRENT STATUS

Current commercial aircraft typically carry fuel in the wings and in some cases the body. The fuel that is in the body may be located in the unpressurized area, sometimes called the center wing, or in the pressurized area, typically the cargo compartment. The fuel that is in the wing is contained by the front and rear spars and the upper and lower wing surfaces and thus is called a wet or integral tank, ie., (there are no rubber bladder cells). Typically the center wing tank is also an integral tank but it is isolated from the personnel compartment by a fume-proof and fuel-proof enclosure as required by Federal Aviation Regulations paragraph 25.967. Fuel tanks such as the center wing tank, which are located within the body contour, are designed to meet the g loads prescribed for emergency landing, FAR 25.561 and 25.963 (Figure 2-1).

The FAR's further require that damage to the airplane main landing gear system during takeoff and landing shall not cause spillage of enough fuel to constitute a fire hazard (FAR 25.721). The fuel tank and landing gear support structure is designed to a higher strength than the gear to prevent fuel tank rupture due to an accidental landing gear overload. This design requirement is further extended to include structural attachments to the wing fuel tank which might be overloaded during a wheels-up or partial wheels-up landing. Pin hinges and engine mounts for example are designed to fail without rupturing the tank.

As indicated previously, some airplanes also have fuel tanks located within the pressurized area, typically the cargo compartment. Particular attention is paid to these designs to minimize the risk of fuel spillage. An example of one such design is shown in Figure 2-2. The tank is composed of an

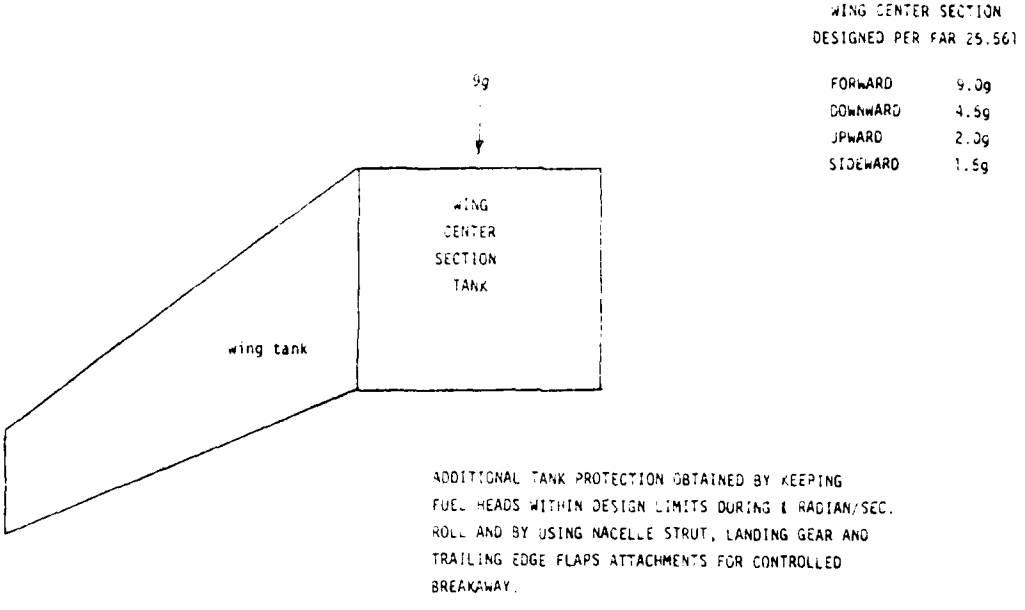


Figure 2-1. Fuel Tank Load Factors

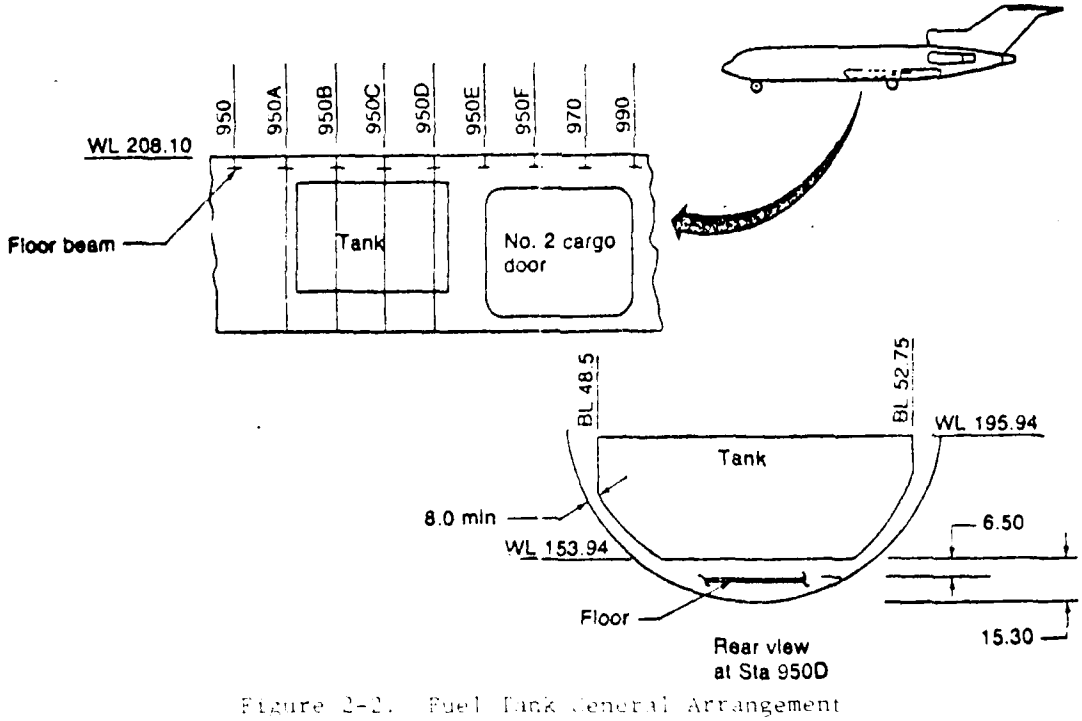


Figure 2-2. Fuel Tank General Arrangement

aluminum honeycomb outer shell with bladder cells inside. The tank is supported from the floor beams in such a manner as to preclude body structure deflections from loading the tank and clearances from adjacent structure are provided around the tank. The outer tank shell is constructed as shown in Figure 2-3.

The fuel and vent lines that connect the auxiliary tanks to the main fuel system incorporate drainable and vented shrouds. Additionally, these lines are either designed to break away from the auxiliary tank or sufficient stretch is provided to accommodate tank movement without causing fuel spillage. Hoses that are required to stretch are subjected to what is referred to as the guillotine test. The hose is pressurized and clamped at both ends to simulate its mounting in the aircraft, then a sharp-pointed load is applied in the middle of the hose. The hose must not leak when stretched to its maximum.

Prior accident history is reviewed to ensure that the tank installation will minimize the possible leakage of fuel. For example, accidents or incidents where the gear has separated are reviewed to ensure that the tank will not be hit by a displaced gear. Also, incidents or accidents where the body has been crushed are reviewed to ensure that there is adequate clearance between the body and the fuel tank. In addition, incidents or accidents where the body has broken are reviewed to ensure that the auxiliary tank is not located where such breaks typically occur.

In summary, it can be said that the body fuel tank design:

- Exceeds FAR requirements
- Is more rugged than center section tank
- Provides considerable clearance
- Allows tank displacement without breakage
- Location results in minimal spillage exposure.

Typical FAR fuel safety structural design requirements and fuel system design requirements are presented on pages 2-4 and 2-5, and in Section 4.

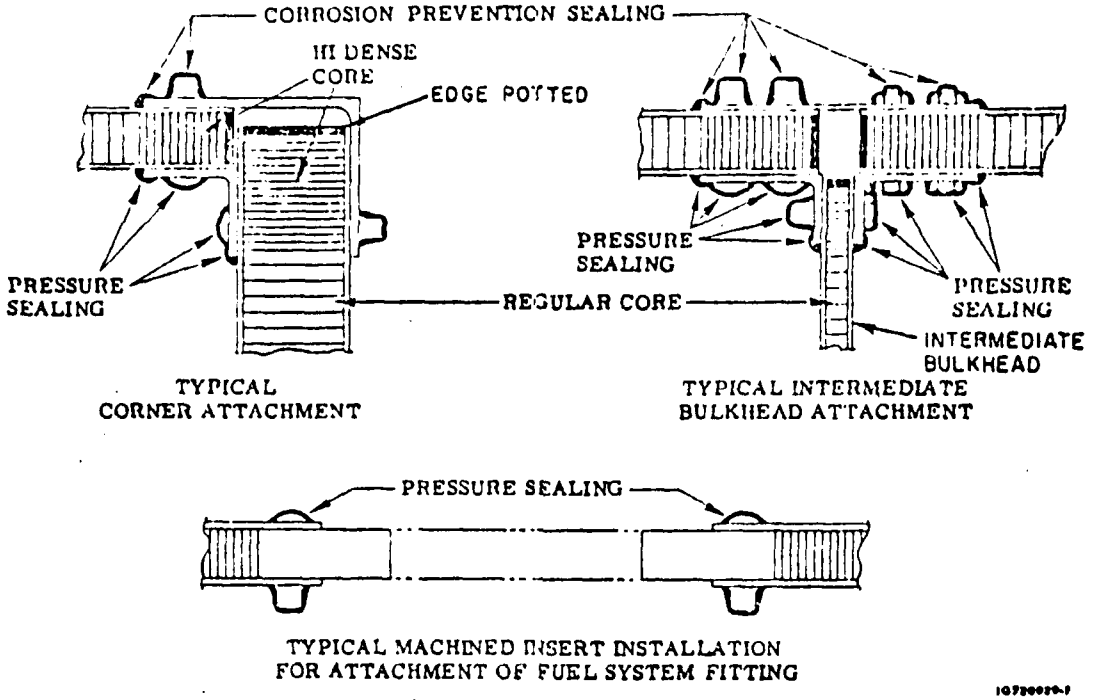


Figure 2-3. Fuel Tank Construction

FAR FUEL SAFETY STRUCTURAL DESIGN REQUIREMENTS

25.721(d)

The main landing gear system must be designed so that if it fails due to overloads during takeoff and landing (assuming the overloads are in the vertical plane parallel to the longitudinal axis of the airplane), the failure mode is not likely to puncture any part of the fuel system in the fuselage.

25.963(d)

Fuel tanks within the fuselage contour must be able to resist rupture, and to retain fuel, under the inertia forces prescribed for the emergency landing conditions in 25.561. In addition, these tanks must be in a protected position so that exposure of the tanks to scraping action with the ground is unlikely.

FUEL SYSTEM DESIGN REQUIREMENTS

- Fuel-carrying lines shall be routed inside of the tank wherever possible. FAR 25.863 and 25.967(e)

- No fittings, valves, sumps, or plumbing that normally carry fuel shall extend below the lower wing surface contour or below major load supporting structural members of the body. FAR 25.963(d)

- Fuel-carrying lines passing through areas where damage could occur due to a crash landing shall be flexible hoses designed and installed to allow a reasonable degree of deformation and stretching without leakage. FAR 25.993

- Primary consideration must be given to fuel/fuel vapor carrying lines passing through pressurized compartments being continuous with no breaks and encased in a pressure-tight continuous shroud drained and vented to ambient. FAR 25.863 and 25.967(e)

- Fuel-vent outlets shall not be located in any probable lighning strike area. FAR 25.954

- Generator feeders shall be isolated from fuel lines and encased in flexible insulating shroud. Feeders shall allow for reasonable degree of stretching or deforming. FAR 25.1359

- Fuel cells shall meet all requirements where applicable. FAR 25.963(b) and 25.967(a)

SECTION 3

EVALUATION OF CONCEPTS

MATRIX OF CONCEPTS VERSUS PENALTY CONSIDERATION

Table 3-1 shows a matrix of concepts for crash-resistant fuel cells/tanks and fuel containment versus major penalty considerations. The concepts include:

- Crash-resistant fuel tanks in the fuselage and wing
- Leading edge reinforcement
- Ductile lower wing skins
- Breakaway fittings
- Alternate fuel tank locations
- Increased compartmentation of integral tanks
- Fuel tank isolation
- Use of external and internal liners
- 35 g integral wing tanks
- Membranes and/or curtains
- Crash energy absorbing devices
- Flow restrictors

The major considerations required to be evaluated in assessing the various concepts include:

Weight

Volume (range)

Cost

TABLE 3-1. MATRIX OF CONCEPT VERSUS PENALTY CONSIDERATIONS (Continued)

CONCEPT	WEIGHT (lbs) (1)	VOLUME/ RANGE	COST $	MAINTAINABILITY	RELIA-BILITY	ADDITIONAL HAZARD?	RETROFIT	EFFECTIVENESS	EQUIVALENT PROTECTION	COMMENTS
Increased com partmentation of integral wing tanks	Extra bulkheads pumps, valves	More unusable fuel	Some increase	More access doors needed for gages etc.		Putting potential break points at most critical structure location in aeroplane not good design	Excessive rework	Less fuel spilled initially, but hazard not eliminated.		
Isolating tanks from expected separation points (e g wing root) by double walls (breakaway fuel cells)	Increased due to double wall at each sep aration plane		Increase		Requires tests to determine		Not feasible	If lose wings and fuel this reduces chance of fuselage fire and reduce kinetic energy of crashing body Will wing loss make fuselage more vulnerable to contact		Great chordwise strength inherent in wing roots also some aircraft have continuous fuel Therefore, build for resistance here and for breakaway at (say) engine plane?
Intumescent paint or external low density foames as cavity liners								Limited		
Integral Wing tanks designed for 35g	10 000 lbs for DC 8 retrofit	Reduce volume by 340 gallons for DC 8 retrofit					DC 8 changes include 3 spar to 4 spar wing, 4 ribs to full bulkheads plus flapper valves, increase string er gage and strengthen front spar	Resist fuel inertia only and not nec essarily direct structural damage		Ref Douglas report LB 31820 Ref also old FAA N P R M and resulting com ments no resulting regulation
Internal liners (e g foam and bonded extend ible film)	3 310 lbs for foam lined LV 880 (6)	Some reduction approx 3%	68 485 (1970 dollars)	How inspect major structure?	Must ensure retention	Static electricity effect? Must en sure retained not to impede transfer	Need frangible bond develop ment, must be compatible with fuel	Penetration by an object large enough to destroy a bulkhead or rib outside capability of concept		See comments on leading edge rein forcement (above 3rd from top)
Membranes or Curtains								DC 7 droptests showed little im provement obtain able, structure damage overwhelmed concepts		Goodyear tests of elastomeric liners, curtains, boot type liner etc. (8)
Crash energy absorbing devices (on leading edge etc.)	Heavy							Nebulous im provement, still allows fuel leakage		
Flow restrictors in fuel (multi cellular poly hedron)	Heavy							Limited (leakage)		

( ) denotes Reference Number

Maintainability

Reliability

Additional hazard

Retrofit

Effectiveness

Equivalent protection

From the matrix it can be observed that for several concepts it is apparent that data has been obtained and initial assessments have been made with regard to a majority, if not all of the considerations. This is particularly true for crash-resistant fuel tanks in the fuselage or wing, leading edge reinforcement, internal liners and breakaway fittings. For other concepts the sparcity of information contained in the matrix indicates there are areas that require further evaluation before assessments can be made.

VOLUME AND WEIGHT PENALTIES

Volume and weight penalties increase the field takeoff length and decrease the range, both of which have implications which apply as obviously to safety considerations as to economics. Due to system complexity, added operation and maintenance requirements, effects on economy, and implications to reduced flight safety, the installation of wing crash-resistant tanks does not appear to be a practical solution to the crash fire prevention problem.

The effect of the range reduction will be reflected in the necessity for additional landings when operating to the limits of the payload range envelope. Airline route structure studies show that approximately 10 percent of the flights require maximum range and payload capabilities. Ten percent of the total flights would therefore require an intermediate landing and takeoff thus increasing the exposures to accidents encountered during the takeoff and landing regimes.

The Civil Aeronautics Board statistical review's for a typical three-year period showed that from 21 percent to 29 percent of aircraft accidents occur enroute, the remaining 71 to 79 percent are associated with landing, takeoff,

and operation on the ground. Actual percent of fatalities associated with this phase of operation is not tabulated; however, a review of the accident resumes included indicate 67 percent are related to airport operations.

It is obvious that the frequency of landing and takeoffs has a direct and important bearing on the frequency of accidents and resulting fatalities. Therefore, any change in aircraft design which might increase the required number of landings and takeoffs must be carefully evaluated for its impact on the total safety problem. From the above statistics it may be calculated that a 10 percent increase in landing and takeoffs could have resulted in a 6.7 percent increase in total fatalities. This probable increase would have exceeded the maximum number attributed to fire even if 100 percent effectiveness is assumed for the crash fire provisions.

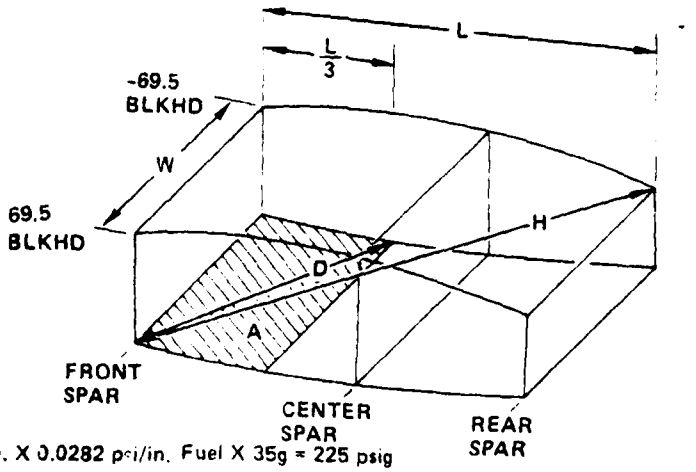
Even on flights which are not limited by maximum takeoff weight, the added gross weight at takeoff and landing will contribute to higher takeoff and landing speeds, which in turn are detrimental to safety. Thus, the added exposure to accidents occurs at higher speed near the ground, tending to compound the danger of each exposure.

DC-8 CENTERWING CRASH RESISTANT TANK INSTALLATION STUDY

The FAA method (Reference 9) for establishing the required dynamic tensile strength of cell material for a so-called crash-resistant tank is based on two quantities. These are the maximum hydrostatic head developed by the 35 g acceleration* and a size factor (diagonal length/area) representing the most critical unsupported cell surface based on the assumption that the structure one-third of the tank chord aft of the impact surface has failed.

Assuming that the DC-8 centerwing tank installation responds as a single tank, the maximum hydrostatic head developed by the 35 g acceleration would be 225 psi. If the tank is assumed to be effectively divided by the center spar into two tanks, the maximum head developed in the forward section alone would be 170 psig. Since the one-third structural failure rule is related to structure and not tankage arrangement, the critical D/A ratio would be the same in either case and is equal to 0.0185. The derivation of these figures is shown in Figure 3-1.

* A proposed FAA rule which was not adopted. Reference [illegible]



W = 139

L = 173

H = 228 in. X 0.0282 psi/in. Fuel X 35g = 225 psig

D = 155 in.

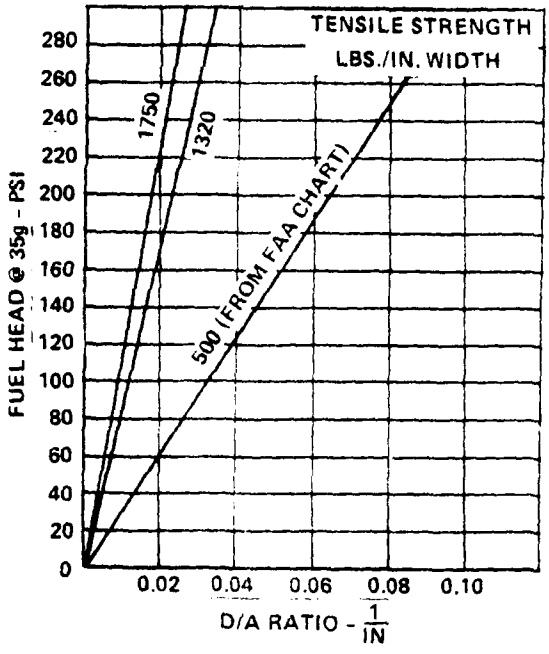
$A = \frac{173}{3}$ in. X 139 in. = 3250 in.^{2}

$\frac{D}{A} = \frac{155 \text{ in.}}{3250 \text{ in.}^2} = 0.0188$

Figure 3-1. Derivation of Cell Design Factors

By referring to the FAA plot of required tensile strength versus hydrostatic head and D/A ratio (Figure 3-2), it can be seen that the required strength even for the assumed divided tank is greater than that available from any of the plotted materials. Assuming the tank to respond as a single cell and extrapolating the FAA data, it appears that a material having a tensile strength of 1750 lb/in. width is required. Extrapolating the data from Reference 9, relating strength and weight of cell material, the minimum weight possible appears to be approximately 0.925 lb/ft^2. If the normal trend of strength versus weight is followed, the required weight appears to be 1.45 lb/ft^2. With the safety factor of 1.75 applied as recommended by U.S. Rubber Company, it is probable that these weights would be of the order of 1.6 lb/ft^2 and 2.55 lb/ft^2, respectively.

Total weights for cell installations based on these materials, as well as comparable weights for an installation based on the two separate tank response, are given in Table 3-2. Also shown is the loss in fuel capacity resulting from the cell installation.



NOTE: DATA OBTAINED FROM FIGURE 3, REFERENCE 9

Figure 3-2. Tensile Strength Versus Hydrostatic Head and D/A Ratio

The following discussion briefly describes the results and comments obtained from several pertinent FAA reports:

FAA RD 71-27 (Reference 3)

Installed bladder cells in DC-7 wing section; filled up voids with styro foam filler.

Fifteen percent volume loss with an extra 46 pounds required for 120 gallons of fuel.

FAA ADS-27 (Reference 4)

Concluded that a Crash Resistant Fuel system imposes a penalty of 9.97 percent fuel volume loss (using a total fuel load of 5512 gallons) and results in a weight decrease of about 1200 pounds. Note: these figures are not typical as a lot of tanks in the DC-7 were already a bladder type (2400 gallons out of the 5512). Volume loss therefore is not representative and the weight loss figure included fuel weight loss.

TABLE 3-2. CRASH RESISTANT FUEL CELL INSTALLATION WEIGHTS

WEIGHT ITEM	BASED ON SINGLE TANK RESPONSE		BASED ON DOUBLE TANK RESPONSE	
	OPTIMUM CELL MATERIAL 1.6 lb/ft^2	PROBABLE CELL MATERIAL 2.55 lb/ft^2	OPTIMUM CELL MATERIAL 1.20 lb/ft^2	PROBABLE CELL MATERIAL 1.90 lb/ft^2
Cell Material (936 ft^2)	1500	2400	1120	1780
*Fitting Weight (3 X present U.S. Rubber fittings)	230	250	220	240
Attachment (nuts, bolts, etc.)	60	60	60	60
Tank Liner (2 X present thickness + 100% for stiffening & structure)	750	750	750	750
Access Doors & Structural Revision	400	400	400	400
TOTAL	2940	3860	2550	3230

*Average number of fittings per cell = 10 (vent & fuel interconnects, access doors, etc.)
Average number of fittings per end cells = 8 (vent & fuel interconnects, access doors, etc.)
Misc. fittings, one each, total = 4 (tank inlet, outlet, capacitance units, etc.)
TOTAL = 116

INSTALLATION FUEL LOSS: Integral Tank Capacity = 26,100 lb
Bladder Cell Capacity = 20,670 lb
Capacity Loss = 5,430 lb

It was apparent that both integral- and bladder-type cells could contain fuel under controlled decelerations which would exceed the human survival envelope. In local impact tests both integral and flexible tanks leaked; the latter at a slower rate.

Portions of fiberglass liner were riveted in for the test specimen, but the authors recommended making the liner one piece of a type of material that wouldn't leave jagged ends.

The cost estimate was 100,[illegible] dollars (1963) for a complete system installation in the number 3 main tank. (Note: there were already some conventional flexible bag tanks that would not cost as much to change over.)

Estimated 300,000 dollars for a new wet-engine [illegible] as related to the larger DC-8 and estimated [illegible] percent of the [illegible] airplane.

Note - a unit gallon cost was taken from the DC-7 work and used in estimates and extrapolated - this is an optimistic [illegible] cost as the DC-7 already had partial bag tanks.

FAA ADS-37 (Reference 5)

No. 3 main tank composed of both integral and bladder - that was converted to crash resistant type - both totally damaged by pole impact.

FAA ADS-19 (Reference 6)

Large transports in 1964 had sufficient strength inboard of the outboard nacelles to cut through 8- to 10- inch diameter trees or poles.

The lower front spar rail and forward section of the lower surface was said to be the most effective area for strengthening. It was claimed that material added was in primary bending and, therefore, not a significant penalty to a revised design structural weight. Material could only be added to a point up to wing break-off shear or bending loads. Convair says 10 g maximum for fuel inertia loads since loads higher than 10 g would cause the wings to be torn off or the fuselage to be crushed.

Crash Loads consist of Internal pressures (fuel head and slosh) plus impact loading and puncturing by stumps and dislodged aircraft parts.

It is stated in Reference 6 that as survivable transport crashes usually occur on or near airports in cleared areas, failure is more frequently due to distributed impact loads and concentrated piercing loads than concentrated impact.

Reference 6 includes detail design concepts - corrugated skin, forward spar variations and Claims that detail design is all important when considering tear resistance and deformity.

The FAA proposed 35 g (which was not adopted) is not in line with recommended 5 g for large transports recommended in the Reference 6 report.

Reference 6 test results showed improved reinforcement with 1% weight increase that would cut down 12- to 18-inch diameter trees.

FAA tests (Reference 5) showed that a 0.04 inch doubler on the top and bottom of a DC-7 wing skin does not appreciably decrease vulnerability of integral tanks to leakage.

Note: 1) tests run were not on ribs but unstiffened skin, and leading edge structure, pipes and components were not represented.
2) the entire wing is not equally strong, outboard tanks are still near ignition sources and contain a lot of fuel that could be hazardous with 'into fuselage' wind conditions.

FAA-DS-70-15 (Reference 7)

This report takes the Reference 6 concept of reinforced leading edges and examines this as well as a foam liner with a bonded extendible film.

Reference 7 concludes that the cost of incorporating two different types of crash resistance in an 80% jet transport fleet is equivalent to the estimated loss involved in about seven accidents. Jet accidents occurring between 1958 and 1968 were such that crash-resistant fuel tanks would not have materially reduced hull losses and fatalities. The character and circumstances of future accidents could be different.

COST BENEFIT TRADE-OFF

A cost benefit analysis of incorporating crash-resistant fuel tanks in a [illegible] transport was conducted in 1970 (Reference 7). This analysis considered the application of a level of crash resistance represented by structural [illegible] in the wing spar area plus a foam layer on the rear surface of the [illegible] and a nylon elastic film attached to the foam.

It was assumed that the load factor is 50 percent and that 50 percent of the occupants would survive an accident and resultant fire even if the airplane did not have crash-resistant tanks and that the other 50 percent would survive

due to prevention of fire with crash-resistant tanks, the analysis determined that post-crash fires would have to be prevented in seven survivable crashes of contemporary transports or three of wide-body transports over a 10-year period for the crash-resistant tanks to be cost/beneficial. If maximum potential benefits are considered at a load factor of 100 percent, where complete credit is given to crash resistant tanks for saving all occupants, the benefits would exceed the costs if post-crash fires were prevented in three contemporary transport crashes or one wide-body transport crash over a 10-year period.

On the basis of these cost/benefit criteria, incorporation of crash-resistant integral fuel tanks in U.S. air carrier aircraft from 1964 through 1974 would not have been cost beneficial. Several aircraft incorporate auxiliary bladder fuel cells in the fuselage below the wing box structure. It would appear that the weight and volume penalties would not be as high for crashworthy fuselage tanks as they are for integral tanks.

SECTION 4

COVERAGE BY EXISTING FARs

The following sections, excerpted from References 11 and 12, pertain to fuel tanks/cells and systems:

25.561 General.

(a) The airplane, although it may be damaged in emergency landing conditions on land or water, must be designed as prescribed in this section to protect each occupant under those conditions.

(b) The structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when -

(1) Proper use is made of seats, belts, and all other safety design provisions;

(2) The wheels are retracted (where applicable); and

(3) The occupant experiences the following ultimate inertia forces acting separately relative to the surrounding structure:

(i) Upward - 2.0 g.

(ii) Forward - 9.0 g.

(iii) Sideward - 1.5 g

(iv) Downward - 4.5 g, or any lesser force that will not be exceeded when the airplane absorbs the landing loads resulting from impact with an ultimate descent velocity of five f.p.s. at design landing weight.

(c) The supporting structure must be designed to restrain, under all loads up to those specified in paragraph (b)(3) of this section, each item of mass that could injure an occupant if it came loose in a minor crash landing.

(Amdt. 3, [illegible], eff. [illegible], 28 FR 5, [illegible])

25.721 General.

(a) The main landing gear system must be designed so that if it fails due to overload in a landing (assuming the overload may occur in the weakest direction), the failure mode is not likely to cause -

(1) For airplanes [illegible] configuration, excluding [illegible], [illegible] loss, the spillage of

enough fuel from any fuel system in the fuselage to constitute a fire hazard; and

(2) For airplanes that have a passenger seating configuration, excluding pilots seats, of 10 seats or more, the spillage of enough fuel from any part of the fuel system to constitute a fire hazard.

(b) Each airplane that has a passenger seating configuration excluding pilots seats, of 10 seats or more must be designed so that with the airplane under control it can be landed on a paved runway with any one or more landing gear legs not extended without sustaining a structural component failure that is likely to cause the spillage of enough fuel to constitute a fire hazard.

(c) Compliance with the provisions of this section may be shown by analysis or tests, or both.

[Amdt. 25-32, 37 FR 3969, Feb. 24, 1972]

25.863 Flammable fluid fire protection.

(a) In any area where flammable fluids or vapors might be liberated by the leakage of fluid systems, there must be means to prevent the ignition of those fluids or vapors, and means to minimize the hazards in the event ignition does occur.

(b) Compliance with paragraph (a) of this section must be shown by analysis or tests, and the following factors must be considered.

(1) Possible sources and paths of fluid leakage, and means of detecting leakage.

(2) Flammability characteristics of fluids, including effects of any combustible or absorbing materials.

(3) Possible ignition sources, including electrical faults, overheating of equipment, and malfunctioning of protective devices.

(4) Means available for controlling or extinguishing a fire, such as stopping flow of fluids, shutting down equipment, fireproof containment, or use of extinguishing agents.

(5) Ability of airplane components that are critical to safety of flight to withstand fire and heat.

(c) If action by the flight crew is required to prevent or counteract a fluid fire (e.g. equipment shutdown or actuation of a fire extinguisher) quick acting means must be provided to alert the crew.

[Amdt. 25-23, 35 F.R. 5676, Apr. 8, 1970]

25.954 Fuel system lightning protection.

The fuel system must be designed and arranged to prevent the ignition of fuel vapor within the system by -

(a) Direct lightning strikes to areas having a high probability of stroke attachment.

(b) Swept lightning strokes to areas where swept strokes are highly probable; and

(c) Corona and streamering at fuel vent outlets.

[Amdt. 25-14, 32 FR 13..., Aug. 11, 1967]

25.963 Fuel tanks: general.

(a) Each fuel tank must be able to withstand, without failure, the vibration, inertia, fluid, and structural loads that it may be subjected to in operation.

(b) Flexible fuel tank liners must be approved or must be shown to be suitable for the particular application.

(c) Integral fuel tanks must have facilities for interior inspection and repair.

(d) Fuel tanks within the fuselage contour must be able to resist rupture and to retain fuel, under the inertia forces prescribed for the emergency landing conditions in 25.561. In addition, these tanks must be in a protected position so that exposure of the tanks to scraping action with the ground is unlikely.

(e) [Reserved]

(f) For pressurized fuel tanks, a means with fail-safe features must be provided to prevent the buildup of an excessive pressure difference between the inside and the outside of the tank.

(Secs. 313(a), 601, and 603, 49 U.S.C. 1354(a), 1421, and 1423; sec. 6(c), 49 U.S.C. 1655 (c))

[Doc. No. 5084, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-40, 42 FR 15043, Mar. 17, 1977]

25.965 Fuel tank installations.

(a) Each fuel tank must be supported so that tank loads (resulting from the weight of the fuel in the tanks) are not concentrated on unsupported tank surfaces. In addition -

(1) There must be pads, if necessary, to prevent chafing between the tank and its supports.

(2) Padding must be nonabsorbent or treated to prevent the absorption of fluids;

(3) If a flexible tank liner is used, it must be supported so that it is not subject to excessive fuel fluid loads; and

(4) Each interior surface of the tank compartment must be smooth and free of projections that could cause wear of the liner unless -

(i) Provisions are made for protection of the liner at these points; or

(ii) The construction of the liner itself provides that protection.

(b) Spaces adjacent to tank surfaces must be ventilated to avoid fume accumulation due to minor leakage. If the tank is in a sealed

compartment, ventilation may be limited to drain holes large enough to prevent excessive pressure resulting from altitude changes.

(c) The location of each tank must meet the requirements of 25.1185(a).

(d) No engine nacelle skin immediately behind a major air outlet from the engine compartment may act as the wall of an integral tank.

(e) Each fuel tank must be isolated from personnel compartments by a fume-proof and fuelproof enclosure.

25.975 Fuel tank vents and carburetor vapor vents.

(a) Fuel tank vents. Each fuel tank must be vented from the top part of the expansion space so that venting is effective under any normal flight condition. In addition -

(1) Each vent must be arranged to avoid stoppage by dirt or ice formation:

(2) The vent arrangement must prevent siphoning of fuel during normal operation:

(3) The venting capacity and vent pressure levels must maintain acceptable differences of pressure between the interior and exterior of the tank, during -

(i) Normal flight operation:

(ii) Maximum rate of ascent and descent; and

(iii) Refueling and defueling (where applicable);

(4) Airspaces of tanks with interconnected outlets must be interconnected;

(5) There may be no point in any vent line where moisture can accumulate with the airplane in the ground attitude or the level flight attitude, unless drainage is provided; and

(6) No vent or drainage provision may end at any point -

(i) Where the discharge of fuel from the vent outlet would constitute a fire hazard; or

(ii) From which fumes could enter personnel compartments.

(b) Carburetor vapor vents. Each carburetor with vapor elimination connections must have a vent line to lead vapors back to one of the fuel tanks. In addition -

(1) Each vent system must have means to avoid stoppage by ice; and

(2) If there is more than one fuel tank, and it is necessary to use the tanks in a definite sequence, each vapor vent return line must lead back to the fuel tank used for takeoff and landing.

25.993 Fuel system lines and fittings.

(a) Each fuel line must be installed and supported to prevent excessive vibration and to withstand loads due to fuel pressure and accelerated flight conditions.

(b) Each fuel line connected to components of the airplane between which relative motion could exist must have provisions for flexibility.

(c) Each flexible connection in fuel lines that may be under pressure and subjected to axial loading must use flexible hose assemblies.

(d) Flexible hose must be approved or must be shown to be suitable for the particular application.

(e) No flexible hose that might be adversely affected by exposure to high temperatures may be used where excessive temperatures will exist during operation or after engine shut-down.

(f) Each fuel line within the fuselage must be designed and installed to allow a reasonable degree of deformation and stretching without leakage.

(Sec. 604, 72 Stat. 778, 49 U.S.C. 1424; Q02

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-15, 32 FR 13256, Sept. 20, 1967]

25.1359 Electrical system fire and smoke protection.

(a) Components of the electrical system must meet the applicable fire and smoke protection requirements of 25.831(c), 25.863, and 25.1205.

(b) Electrical cables, terminals, and equipment in designated fire zones, that are used during emergency procedures, must be at least fire-resistant.

(c) Main power cables (including generator cables) in the fuselage must be designed to allow a reasonable degree of deformation and stretching without failure and must -

(1) Be isolated from flammable fluid lines; or

(2) Be shrouded by means of electrically insulated flexible conduit, or equivalent, which is in addition to the normal cable insulation.

(d) Insulation on electrical wire and electrical cable installed in any area of the fuselage must be self-extinguishing when tested at an angle of 60° in accordance with the applicable portions of Appendix F of this part, or other approved equivalent methods. The average burn length may not exceed 3 inches and the average flame time after removal of the flame source may not exceed 30 seconds. Drippings from the test specimen may not continue to flame for more than an average of 3 seconds after falling.

(Sec. 604, 72 Stat. 779, 49 U.S.C. 1424)

[Doc. No. 5066, 29 F.R. 18291, Dec. 24, 1964, as amended by Amdt. 25-17, 33 F.R. 8066, June 20, 1968; Amdt. 25-22, 37 F.R. 3972, Feb. 24, 1972]

121.227 Pressure cross-feed arrangements.

(a) Pressure cross-feed lines may not pass through parts of the airplane used for carrying persons or cargo unless -

(1) There is a means to allow crew-members to shut off the supply of fuel to these lines; or

(2) The lines are enclosed in a fuel and fume-proof enclosure that is ventilated and drained to the exterior of the airplane.

However, such an enclosure need not be used if those lines incorporate no fittings on or within the personnel or cargo areas and are suitably routed or protected to prevent accidental damage.

(b) Lines that can be isolated from the rest of the fuel system by valves at each end must incorporate provisions for relieving excessive pressures that may result from exposure of the isolated line to high temperature.

121.229 Location of fuel tanks.

(a) Fuel tanks must be located in accordance with 121.255.

(b) No part of the engine nacelle skin that lies immediately behind a major air outlet from the engine compartment may be used as the wall of an integral tank.

(c) Fuel tanks must be isolated from personnel compartments by means of fume- and fuel-proof enclosures.

SECTION 5

NTSB TRANSPORT ACCIDENT DATA

A limited-scope review and evaluation of 27 survivable transport accidents covering the ten-year period from 1969 to 1978 was performed. The results for these 27 accidents involving transport-category aircraft show the most prevalent type of damage was to fuselage structure (18), followed by landing gears (17) and wing structure (13). Both fuselage- and wing-mounted engine configurations were included in the evaluation. The occurrence of engine separation and post-crash fires were shown to be equal for both types of engine-mounted configurations. A higher percentage of occupants sustained serious injuries or fatalities in fire-related accidents as compared to non-fire-related accidents. In 12 of the 16 accidents in which fire occurred, at least one fatality or serious injury resulted. In the 16 fire-related accidents involving 1406 occupants, nearly 41 percent (573) suffered a serious injury or fatality. In the 12 non-fire-related accidents involving 1146 occupants, only 11 percent (125) sustained a serious injury or fatality. Of the 16 fire occurrences, between 62.5 to 87.5 percent (10 to 14) may be attributed to a wing failure or engine separation. Of the 18 incidents resulting in fuselage damage, 14 sustained extensive fuselage damage which can be considered of a nature that could potentially cause post-crash fires from ruptured fuel cells and/or lines contained in the fuselage. Generally, the significant fuselage damage resulted in break-up of the airframe into three or more sections.

The results of this brief evaluation indicate that determining whether improvement of fuel retention during transport airport crashes can be achieved, relates to a careful analysis of crash data history to explore modes of failure. An 18-month research program (Reference 13) funded by FAA/NASA, involving the three domestic wide-body airframe manufacturers is

anticipated to be initiated near the end of 1979 for the purpose of developing crash scenarios and recommending future test and analysis effort for the development of improved crashworthiness, if required, for transport-category airplanes.

The development of crash scenarios on this planned research program involves a comprehensive review and evaluation of transport airplane accident data for the period of 1964 to 1979 to define a range of crash situations in the takeoff, approach and landing modes. During the course of this investigation a review will be made of fire-related incidents with regard to potential causes as well as the relationship between fire occurrence, airplane configuration, and structural damage. This study will be particularly pertinent to the evaluation of crash-resistant fuel cells in that the installation of fuel tanks/cells in critical areas will be thoroughly assessed.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- Within the current state of the art it is feasible and current practice to install crashworthy fuel cells in the fuselage cargo compartments on a retrofit or new design basis.

- It is not feasible, nor necessarily desirable, within the current state of the art to install crash-resistant fuel cells in the wings of conventional transport aircraft.

- The existing Federal Aviation Regulations are adequate to cover the use of crash-resistant fuel cells in transport aircraft. Further definition of fuel-tank crashworthiness should evolve from total aircraft crashworthiness considerations.

RECOMMENDATIONS

- Prior to recommending additional funded Research and Development programs involving NTSB accident data review and evaluation, the results of the anticipated transport aircraft crashworthiness study involving the wide-body airframe manufacturers should be reviewed. If warranted by the results of additional accident data evaluation, design criteria to be used in the development of improved crash-resistant fuel cells should be defined.

- Recommend that the FAA support the implementation of the CRC Aviation Fuel Safety 1975 Report, No. 482 Reference 14) regarding improved accident reporting which states the following:

  Recommendations on Improved Accident Reporting - Aircraft accidents are reported using standard codes and terms. In the case of General Aviation, either NTSB Form 6120 is completed by the pilot operator or NTSB Form 6120.4 is completed by the investigator. Both ask for data on fuel by volume and grade but do not seek information on mode of fuel release.

In the case of Air Carrier accidents, NTSB Form 6120.2 is used in reporting all civil aircraft accidents involving aircraft exceeding 12,500 pounds takeoff weight, helicopters and Alaskan air carriers. Usually this form is supported by attached statements as well as the report of the Investigation Team. Complete though this form is, it still lacks certain vital information relevant to fuel fires; unfortunately the usual attachments to this form in an Accident File also lack the information. A revision of the Form should focus attention on the need for information relative to fuel and fires.

The suggested additions to Form 6120.2 cover the following items:

Section V - Cause of fatalities, Fire, Asphyxiation or Trauma.

Section VII - Exit Time. Exits Used. Location of Exits and Fatalities.

Section VIII - Fuel Aboard by Volume and Grade. Source of Fuel Release. Fire Extinguishing System.

Section X - Site Conditions, e.g., Surface.

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- DRAFT REPORT -

TECHNICAL SUB-GROUP ON ANTI-MISTING KEROSENE OF THE SAFER TECHNICAL GROUP ON POST-CRASH FUEL-FIRE HAZARD REDUCTION SYSTEMS & TECHNIQUES

SEPTEMBER 1979

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I. INTRODUCTION

Anti-misting kerosene (AMK) has reached the current level of development as the latest in the search for a "crash safe" aircraft turbine fuel. The fundamental consideration in crash safe fuel development has been to produce a fuel which will not result in the fine fuel mists which will propagate a flame from an ignition source to a larger supply of fuel in a rapid manner. These mists are generated by the high shear rate expulsion of fuel from a small tank opening or by air shear/breakup of larger masses of fuel expelled during deceleration. Preventing the rapid development of a large fire arounc an aircraft involved in an impact survivable accident where fuel tank rupture occurs can allow more time for passenger and crew evacuation and result in a higher rate of survivability in this type accident.

The anti-misting quality is imparted to the fuel by the addition of low concentrations of shear-sensitive hydrocarbon polymers. The additive currently being evaluated by the FAA is known as FM-9. FM-9 is a proprietary material produced by Imperial Chemical Industries in the United Kingdom.

Testing complimentary to the FAA program is going on in the UK. The joint program is being conducted under an agreement whereby the proprietary rights of ICI are protected. The current agreement will culminate near the end of 1980 in a decision to continue further development of AMK as a concept or to discard AMK as being improbable of development for commercial aircraft service.

The anti-misting additive has been shown to be effective in reducing flame propagation through mists of kerosene fuels of contemporary flash point levels (100°F and above). Tests using anti-misting additive in wide-cut fuels of low flash point (near 0°F) and high volatility (e.g. JP-4, Jet B) show little relative effectiveness in similar tests.

Reductions in misting characteristics have been found by gelling or emulsifying fuels. Previous investigations have found these methods of improving anti-misting qualities to be severely lacking in other critical aspects such as holdup of fuel in the aircraft tankage.

Other fuel additives which improved anti-misting qualities have been investigated, but are not currently being evaluated for aviation fuels.

II. SUMMARY

The Sub-group on Anti-misting Kerosenes (AMI) of the SAFER Technical Group on Post Crash Fuel-Fire Hazard Reduction Systems & Techniques has reviewed the development status of AMK and has reviewed the research efforts of the FAA sponsored programs. This review has been centered on the programs under way in a joint effort between the United States and the United Kingdom to evaluate FM-9, a candidate fuel additive offered by Imperial Chemical Industries.

A regular quarterly meeting of all the participants in the US/UK effort on FM-9 was held to report on the progress of the individual programs. This meeting provided the Sub-group with a condensed, but comprehensive review of the current major activity in the area of AMK development. The information received during this meeting and the collective previous experience of the Sub-group members form the basis for the technical evaluation made at this time.

The Sub-group finds that the evolution of an AMK for commercial aircraft offers a potential improvement in crash safety by limiting the spread of fire from an ignition source through the fuel mist that occurs when fuel is released from broken or punctured tanks. The group finds that the state of optimization of AMK is such that no rule making is possible at this time.

The Sub-group finds that the established programs are covering areas of interest in FM-9 evaluation and development such as basic fuel rheology, the effects of air shear parameters, degradation of the AMK to improve relight characteristics, systems compatibility and crash tests.

The measurement of anti-misting quality and the control and evaluation of this parameter during the testing are the areas most in need of improvement. The Sub-group has made other specific recommendations regarding the evaluation of AMK which are enumerated elsewhere in this report.

III. SPECIFIC COMMENTS ON PROGRAMS

The US/UK program to evaluate FM-9 looks at many aspects of the effectiveness and of the utilization of this material to produce an AMK. This broad spectrum evaluation is briefly described below with a mention of the participants and their sponsors.

RHEOLOGY & PROPERTY MEASUREMENT

The Jet Propulsion Laboratory (NASA) and the Southwest Research Institute (FAA) are investigating the fundamental properties of AMK made with FM-9. These tests evaluate the apparent viscosity and viscosity variations of the AMK as a function of shear, temperature and test methods. Hysteresis due to previous history of the materials are investigated. JPL is involved in an attempt to model the air shearing and droplet formation when AMK is introduced into an air stream. SWRI is developing a spinning disc method of evaluating the relative flammability characteristics of AMK which has been worked by a degrading device or by use in a typical system.

There are several methods of measuring properties of an AMK. These include:

1) A filtration test where the time to pass a certain amount of fluid through a specified metal screen is measured.
2) The mist flammability of the sample when subjected to a specified set of reproducible conditions.
3) A viscosmeter which measures flow rate vs. pressure drop through a specified bed of glass beads.
4) An orifice cup where the time to drain the fluid from a standardized container through a fixed orifice is measured.

DEGRADATION

"Degradation" is the change of AMK from its first formed state to where the properties of the mixture approach that of the base fuel used in producing the AMK. This process may also be described as a "restoration" of these properties if the basis is established as that of the neat fuel before the additive is mixed.

(III. Specific Comments - Cont'd.)

JPL, SWRI (FAA), and the Royal Aircraft Establishment are involved in degrading methods development. The RAE has examined mechanical degraders that shear the material at high rates. These degraders have shown rather high power consumption requirements.

JPL is to examine chemical degrading. SWRI has examined the degradation which results from passing the fuel through a glass bead packed tube. This method has shown promise in that the power requirements are reported to be lower than those of the mechanical degraders.

PRODUCTION OF AMK

The supplier of FM-9, Imperial Chemical Industries, is involved in development of methods to mix FM-9 with base fuel to produce AMK. They are also involved in the development of production quality control methods. This work has not progressed to the point where ICI can permit any researcher to produce his own AMK using FM-9 additive and to confidently obtain a product equivalent to that which is shipped from the ICI facility. Consequently all researchers using FM-9 must have their test fuels shipped from the ICI facility in Wilmington, Delaware. A 30 day shelf life is guaranteed by ICI.

There is an intent on the part of the FAA to encourage the development of alternate AMK producing additives or processes. The funding for such activities is currently secondary to the evaluation of FM-9.

WATER COMPATIBILITY

The RAE is examining the long term effects of water pickup on FM-9. This test involves carrying some FM-9 in the vented tip tank of a [illegible] airplane. There are other efforts to examine water effects, but these efforts vary with the researcher.

9/24/78

(III. Specific Comments - Cont'd.)

FUEL SYSTEM SIMULATOR TESTS

Lockheed, Georgia, has completed an investigation of the effects of FM-9 concentration on the performance of various fuel subsystems of the C-141 in a simulator for the FAA. They have also examined the effects on AMKs made with various concentrations of FM-9 of their use in the simulator. This testing is reported in FAA-RD-79-52 dated May 1979. The simulator testing was followed by tests of fuel samples in an air gun for evaluation of degradation. New fuel was used in these tests.

A commercial fuel system simulator test series is being considered (FAA/USAF) using the Douglas DC-10 fuel system simulation. This test series would look at other aspects of the fuel subsystems sensitive to AMK and would be run at a single additive concentration. An air gun test is proposed for fuel degradation and fuel quality evaluation. This test series will be run with new fuel in each test and will require large quantities of test fuel to be shipped from coast to coast. The tests are described by a preliminary work statement supplied to the Sub-group members.

ENGINE COMPONENTS TESTS

A program is being started (NASA/FAA/USN) with Pratt & Whitney to look at various components of the JT8D engine fuel system in order to assess the use of FM-9 in these and other engines. The proposed tests were described in a preliminary statement of work supplied to the Sub-group members. A fuel controller, filter, pump, injector, and combustor will be examined using undegraded and degraded fuel. An RAE developed degrader will be used in this test. An attempt will be made to also reuse fuel degraded by previous testing. This may reduce the expense of fuel procurement.

FUEL AIR-SHEAR TESTS

FAA (NAFEC, Atlantic City), is conducting tests to examine AMKs under controllable conditions. Fuel is released from the leading edge of an airfoil into an air stream. An ignition source is provided. The propagation of flame

(III. Specific Comments - Cont'd.)

through the resultant fuel mists can be examined under various fuel release rates and using different airspeeds. Many test runs are planned to determine the effects of the various parameters involved. The results of these tests are to be correlated with large scale crash tests.

LARGE SCALE CRASH TESTS

Large scale crash tests of surplus "Neptune" patrol aircraft are planned to examine the performance of AMK in large aircraft under simulated crash conditions. Wing mounted turbine engines on the aircraft will be operating and an aft mounted engine will be simulated. The fuel tanks will be intentionally ripped open. Open flames will simulate additional sources of ignition. Multiple tests will be run to provide an evaluation over a range of controllable parameters.

SUBSEQUENT TESTING

Testing is planned to evaluate other candidate AMKs than FM-9. The friction reducing additives used in pipelines and other polymers may give anti-misting qualities when mixed in Jet A turbine fuels. Previous offerings of this type were rejected due to undesirable side effects, which are thought to be unique to their particular makeup.

Further ground testing in actual aircraft and engines and eventual flight testing is anticipated depending on the results of previous testing.

IV. EVALUATION OF METHOD

An evaluation of AMK has been conducted following the charter given to the Sub-groups. The results of this evaluation and specific comments follow in the text of this section and in the Conclusions & Recommendations sections which follow.

The use of AMK will significantly reduce the fire and explosion hazard in a survivable accident by significantly reducing the propagation of flame through fuel mists such as might occur during an aircraft crash. Flame from an ignition source could in some cases be prevented from spreading to an area where a larger fuel supply is available. The full scale crash tests planned by the FAA will produce additional information on this question.

The effects of FM-9 on static charge generation and relaxation is unknown. Any effects on micro-organic growth are unknown.

The effects of FM-9 on aircraft systems is to be evaluated in planned programs. The examination of heat transfer characteristics is significant to the assessment of adequate oil cooling and to the cooling of electrical pump motors.

The evaluation and development program for AMK is directed toward a fuel with properties that will be usable in current aircraft with minimum modifications. AMK is not yet acceptable for use in existing aircraft. Only opinions are available on when AMK could be introduced. It appears to be at least 10 years away, but possible breakthroughs could shorten this time.

The FM-9 additive does not appear to have a significant aircraft weight penalty associated with its use. Unusable fuel volume may be unchanged. Engine driven mechanical degrader power loss is under study and it appears it may be reasonably acceptable when developed.

The effects of FM-9 on aircraft system maintenance are undefined, however, they appear to be manageable. AMK effects on system reliability are undefined but are under study, e.g., critical engine component tests. A strong emphasis on

(IV. Evaluation of Method - Cont'd.)

maintaining the anti-misting quality of the AMK "in the aircraft" is a requirement of the FAA development program. Some quality control methods are being developed, e.g., viscosity measurements, filtration tests, and mist flammability tests.

V. COVERAGE BY EXISTING REGULATIONS

There are no current regulations covering anti-misting kerosenes. It is too soon to suggest regulations to cover these fuels.

VI. CONCLUSIONS

- The AMK concept offers a potential improvement in crash safety with relatively little impact on the aircraft operation and maintenance.

- No regulatory action is possible at this time.

- The FAA has established a very ambitious schedule for a decision on whether to pursue FM-9, which calls for a decision near the end of 1980. The potential of an AMK development should not end on the results of the current program.

- The reuse of AMK in test programs is highly questionable unless extensive characterization data is taken on the fuels.

- Airgun flammability tests run to date are only of the go/no-go variety and give only gross comparisons. They do not evaluate velocity effect variations.

- Current quality control methods are insufficiently defined.

VII. RECOMMENDATIONS

- The development of an AMK should continue and be expanded.

Degradation Concepts

- Continue investigation of degrading concepts. SWRI developments are encouraging.

- Degrading should also be discussed with experts in the areas of membrane technology, lubrication technology, and various ultrasonic concepts.

- There should be a standardization of degradation, both as to method of measurement and definition of degree.

Fuels

- The present formulation of FM-9 with carrier fluid should be given a different designation to separate test data from those obtained without carrier fluid.

- A strong emphasis should be put on quality control of the fuels used by the partipants.

- Tests involving flammability should be done with a specification base fuel at the minimum allowable flash point. The flash point of most of the fuel from ICI used in flammability tests appears to be about 20°F above the minimum allowed by specification.

- A complete fuel property data record should be maintained on all base fuel used.

- The development of an on-site mixing capability of fuel used for test purposes should be a requirement of the FAA program for logistic and economic reasons.

(VII. Recommendations - Cont'd.)

Engine Compatibility

- A new task should be integrated into the front of the engine compatibility testing program to evaluate the effects of fuel degradation due to testing of engine fuel system components and the effects of fuel degradation using the RAE degrader. Either the preceding should be done or new fuel should be used for each test.

Systems Compatibility

- The airframe contractor should run the same battery of quality control/fuel characterization tests on the fuel used in the system compatibility testing as will be done in the engine compatibility testing.

Water Tolerance

- An investigation of water content methods is required (if water is a problem and it may be).

Fuel Handling

- A plan identifying the method of introduction of the additive into the base fuel at the airport and the AMK into the airplane should be set down so that specific problems can be identified and worked early. This will give a better view of the realistic use of AMK on the airport.

- The electrostatics aspects of the AMK should be examined.

- The effects of standing following use in tests (recovery of properties) should be examined.

BOEING RESEARCH & DEVELOPMENT
COMPARTMENT INTERIOR MATERIALS

- FIRE TEST METHODOLOGY
- INTERIOR MATERIALS DEVELOPMENT
- HEAT RESISTANT ESCAPE SLIDES

FIRE TEST METHODOLOGY

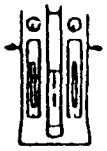
MATERIALS DEVELOPMENT PROGRAMS HAVE SHOWN THERE IS A LACK OF:

- TEST METHODS TO CONSISTENTLY MEASURE MATERIAL FLAMMABILITY, HEAT RELEASE, SMOKE RELEASE AND TOXICANT PRODUCTION
- A METHODOLOGY TO RELATE LABORATORY VALUES TO REAL FIRE PERFORMANCE
- COMBUSTION TOXICOLOGY LABORATORY TESTS WITH CONDITIONS AND RESULTS REALISTICALLY RELATED TO AIRPLANE FIRES

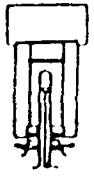
EXISTING LABORATORY TEST METHODS



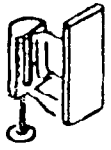
BUNSEN BURNER
- FLAMMABILITY



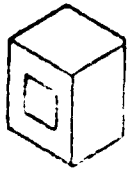
LIMITING OXYGEN INDEX
- IGNITABILITY



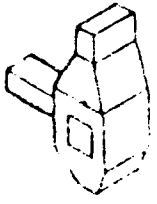
THERMOGRAVIMETRIC ANALYSIS
- DECOMPOSITION TEMPERATURES
- DECOMPOSITION RATE



FLAME SPREAD-E-162
- FLAME SPREAD
- HEAT RELEASE



NBS SMOKE CHAMBER
- SMOKE ACCUMULATION
- TOXIC GAS ANALYSIS



RELEASE RATE APPARATUS
- HEAT RELEASE
- SMOKE RELEASE

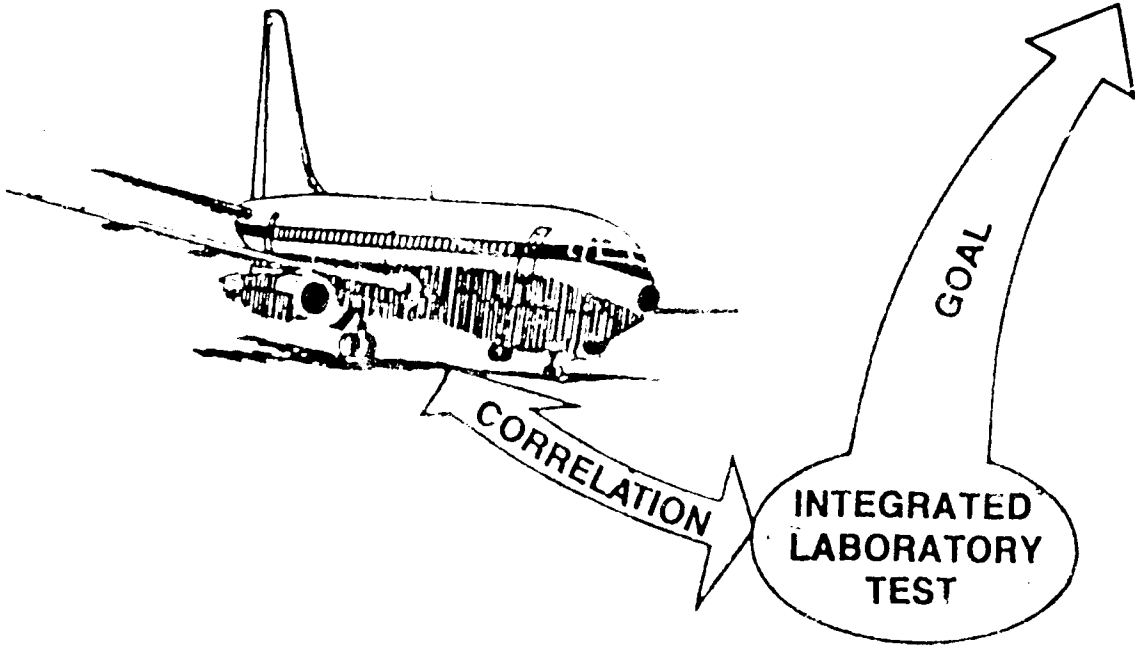
A NEW TEST METHODOLOGY CONCEPT

CABIN ENVIRONMENT TOLERANCE LIMITS

- TEMPERATURE
- VISIBILITY
- TOXIC GAS CONCENTRATION
- OTHERS

FUTURE MATERIALS

SELECTION BASED ON PREDICTED MATERIAL PERFORMANCE IN CABIN FIRE ENVIRONMENT



MATERIALS' PROPERTIES

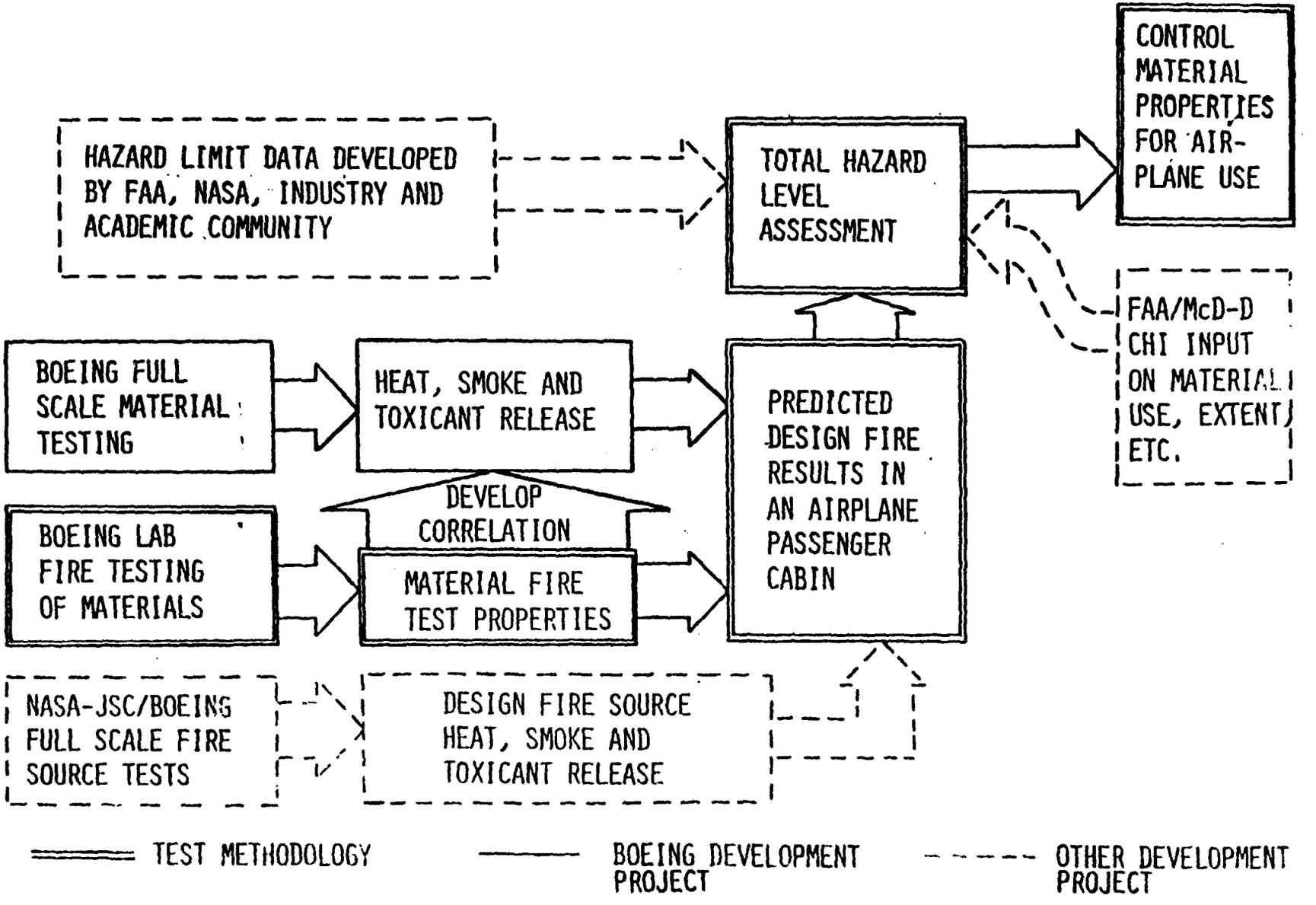
- HEAT RELEASE
- SMOKE RELEASE
- TOXIC GAS EMISSION
- FLAMMABILITY
- OTHERS

AD-A099 147 FEDERAL AVIATION ADMINISTRATION WASHINGTON DC OFFICE--ETC F/G 1/2
SPECIAL AVIATION FIRE AND EXPLOSION REDUCTION (SAFER) ADVISORY --ETC(U)
JUN 80 J W ENDERS, E C WOOD
UNCLASSIFIED FAA-ASF-80-4-VOL-2A NL



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BOEING FIRE TEST METHODOLOGY DEVELOPMENT



COMBUSTION TOXICOLOGY EXPERIMENTATION

- o USE RADIANT HEAT EXPOSURE
- o USE FLAME IGNITION
- o EXPOSE PANELS FROM ONE SIDE
- o VARY PANEL SIZE
- o VARY HEATING RATE

INTERIOR MATERIALS DEVELOPMENT

- ESTABLISH GOALS
- EVALUATE AND DEVELOP MATERIALS

FLAMMABILITY, SMOKE AND TOXICITY GOALS

FLAMMABILITY

- FAR 25.853 AMMENDMENT 25-32
- FLAME SPREAD INDEX MAXIMUM 25
  - APPARATUS–ASTM E 162

SMOKE

NBS CHAMBER, 2.5 WATTS CM^2 HEAT FLUX:

4.0 MINUTES

- LARGE AREA, D_S MAXIMUM 50
- SMALL AREA, D_S MAXIMUM 200

TOXICITY

NBS SMOKE CHAMBER

GAS EMISSION (PPM) TIME	CO	HCN	HF	HCl	SO_2	NO_2
4.0 MINUTES	3500	150	50	500	100	100

R

SCOPE - MAJOR MATERIALS SYSTEMS

DECORATIVE SANDWICH PANELS

COMPRESSION MOLDED FG.

THERMOPLASTICS

TRANSPARENCIES

INSULATION AND COVERINGS

SANDWICH AIR DUCTS

UPHOLSTERY FABRICS

FLEXIBLE DUCTS AND TUBING

FIBERGLASS LAMINATES

FLEXIBLE FOAMS

CARPETS AND UNDERLAYS

RIGID FOAMS

CARGO LINING

SCOPE - SECONDARY MATERIALS SYSTEMS

HIGH PRESSURE LAMINATES

COATED FABRICS

DRAPERY FABRICS

ELASTOMERS

SEALANTS AND ADHESIVES

ADVANCED COMPOSITES

FLOOR PANELS

POTTING COMPOUNDS

METAL LAMINATES

HEAT RESISTANT ESCAPE SLIDES

- STUDY HUMAN TOLERANCE LEVELS, ACCIDENT REPORTS, AND FIRE CHARACTERISTICS TO DEVELOP SLIDE HEAT RESISTANCE CRITERIA AND OBJECTIVES

- EVALUATE NAFEC PROPOSED LABORATORY FIRE TEST METHOD FOR CAPABILITY TO DETERMINE HEAT RESISTANCE OF SLIDE CONSTRUCTION AND MATERIALS

LOCKHEED PRESENTATION

TO THE

SAFER COMMITTEE

FIRE SAFETY IMPROVEMENT

SAFER PRESENTATION

- FLAMMABILITY IMPROVEMENT CONSTRAINTS
  - WEIGHT
  - FABRICABILITY
  - AVAILABILITY
  - DURABILITY
- L-1011 FLAMMABILITY IMPROVEMENTS
  - INSULATION COVER
  - WINDOW REVEAL
  - BACKS AND PANS

FLAME RESISTANCE REQUIREMENTS

	FAA - FAR 25.853B	L-1011 REQUIREMENTS
	12 SEC VERTICAL 15 SEC FLAME-OUT	12 SEC VERTICAL 15 SEC FLAME-OUT
MAT'LS AND CONST.	● THERMOFORMED PARTS ● INJECTION MOLDED PARTS ● INSULATION BLANKETS AND COVERINGS ● RIGID DUCTING ● CARGO LINERS ● FIBERGLASS LAMINATE ● ELECTRIC CONDUIT ● DECORATIVE FLOOR COVERINGS ● (VINYL/GLASS)	
	● CARPETS ● UPHOLSTERY ● SEAT CUSHIONS ● DRAPERIES AND CURTAINS ● TRAYS AND GALLEY FURNISHINGS	● CARPETS ● UPHOLSTERY ● SEAT CUSHIONS ● DRAPERIES AND CURTAINS ● TRAYS AND GALLEY FURNISHINGS

FLAME RESISTANCE REQUIREMENTS

	FAA REQUIREMENTS FAR 25.853A	L-1011 REQUIREMENTS
	60 SEC VERTICAL 15 SEC FLAME-OUT 3 SEC DRIP EXT.	60 SEC VERTICAL 5 SEC FLAME-OUT 3 SEC DRIP EXT
MAT'LS AND CONST.	● INTERIOR CEILING PANELS ● SIDEWALL PANELS ● FLOORING ● OVERHEAD STOWAGE ● PARTITIONS ● GALLEY STRUCTURE ● SERVICE CENTERS ● CLOTHES CLOSETS	● INTERIOR CEILING PANELS ● SIDEWALL PANELS ● FLOORING ● OVERHEAD STOWAGE ● PARTITIONS ● GALLEY STRUCTURE ● SERVICE CENTERS ● CLOTHES CLOSETS

THERMOFORMED PARTS
INJECTION MOLDED
INSULATION BLANKETS AND COV.
FIBERGLASS LAMINATES
RIGID DUCTING
CARGO LINERS
ELECTRIC WIRE AND CONDUIT
DECORATIVE FLOOR COVERINGS

FLAMMABILITY IMPROVEMENT CONSTRAINTS

- WEIGHT
- FABRICABILITY
  - FORMING TEMPERATURE REQUIREMENTS
  - COLOR
    - DYE
    - PAINT
  - BONDABILITY
  - INTERLAMINAR ADHESION
- AVAILABILITY
- DURABILITY
  - COLOR RETENTION
  - DIMENSIONAL STABILITY
  - CHEMICAL STABILITY

LOCKHEED 10 YEAR PROGRAM
INTERIOR FLAMMABILITY

MATERIAL STUDIES

- CABIN MATERIALS (12)
- FIRE RETARDANTS & COATINGS (5)

TEST TECHNIQUES (11)

BASIC RESEARCH

- SMOKE EMISSION (3)
- ANALYTICAL METHODS
- CHEMICAL MECHANISMS (5)

DESIGN STUDIES

- SAFETY ANALYSIS (2)
- CRITERIA (2)
- CONFORMANCE (2)
- WASTE CONTAINMENT
- ELECTRICAL DESIGN
- FIRE MANAGEMENT (5)

FLAMMABILITY PROPERTIES
WINDOW REVEALS

	GLASS/ POLYESTER	GLASS/PHENOLIC	GLASS/PHENOLIC CRUSHED CORE
FAR 25.853			
FLAME TEST (60 SEC)			
AFTER FLAME	5.9 SECONDS	0	0
BURN LENGTH	4.7 INCHES	0.6 INCHES	3.4 INCHES
SMOKE DENSITY (Ds)			
90 SECOND	250	42	31
240 SECOND	310	130	45

- 850 SQUARE FEET PER A/C
- CHANGE IMPACT* 90 LB WEIGHT DECREASE PER A/C
  $3500 COST DECREASE PER A/C

*GLASS/PHENOLIC TO CRUSHED CORE ONLY. GLASS/POLYESTER TO GLASS/PHENOLIC NO IMPACT

FLAMMABILITY PROPERTIES
OVERHEAD STORAGE CABINETS
BACKS AND PANS

	GLASS/POLYESTER	KEVLAR/PHENOLIC
FAR 25.853		
FLAME TEST (60 SEC)		
AFTER FLAME	0 SECONDS	4.0 SECONDS
BURN LENGTH	1.7 INCHES	2.5 INCHES
SMOKE DENSITY (Ds)		
90 SECONDS	108	15
240 SECONDS	110	35

- 900 SQUARE FEET PER A/C
- CHANGE IMPACT 60 LB WEIGHT DECREASE PER A/C
  $3000 COST INCREASE PER A/C

FLAMMABILITY PROPERTIES
INSULATION COVER

	TEDLAR (POLYVINYL FLUORIDE)	KAPTON (POLYIMIDE)
FAR 25.853 FLAME TEST (60 SEC)		
AFTER FLAME	0	0
BURN LENGTH	4.3 INCHES	0.3 INCHES
SMOKE DENSITY (Ds) 240 SECONDS	10	3-4
LIMITING OXYGEN INDEX (% OXYGEN TO BURN)	18-20	50-55
HEAT DEFLECTION TEMP	107°C	220°C

- 29000 SQUARE FEET PER A/C
- CHANGE IMPACT 88 LB WEIGHT INCREASE PER A/C
  $19,000 COST INCREASE PER A/C